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PRELIMINARY DESIGN
OF TWO SPACE SHUTTLE
FLUID PHYSICS EXPERIMENTS

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ABS: The mid-deck lockers of the STS and the requirements for operating an experiment in this region are described. The design of the surface tension induced convection and the free surface phenomenon experiments use a two locker volume with an experiment unique structure as a housing. A manual mode is developed for the Surface Tension Induced Convection experiment. The fluid is maintained in an accumulator pre-flight. To begin the experiment, a pressurized gas drives the fluid into the experiment container. The fluid is an inert silicone oil and the container material is selected to be comparable. A wound wire heater, located

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FINAL REPORT

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16. Abstract

Concepts for the operation of two fluid experiments in the mid-deck region of the STS were developed. Based upon these concepts a preliminary design for each experiment is made. The two experiments are the Surface Tension Induced Convection experiment and the Free Surface Phenomena experiment. The mid-deck lockers of the STS are described and the requirements for operating an experiment in this region are described. For each locker the experiment design uses a two locker volume with an experiment unique structure as a housing.

For the Surface Tension Induced Convection experiment a manual mode is developed. The fluid is maintained in an accumulator pre-flight. To begin the experiment a pressurized gas drives the fluid into the experiment container. The fluid is an inert silicone oil and the container material is selected to be compatable. A wound wire heater is located axisymmetrically above the fluid. The heater is designed to deliver three wattages to a spot on the fluid surface. These wattages vary from 1-15 watts. The fluid flow is observed through the motion of particles in the fluid. The experiment container is illuminated by a 5 mw He/Ne laser. Scattered light is recorded on the film plane of a 35mm camera.

The free surface phenomena experiment consists of a trapezoidal cell which is filled from the bottom. The fluid is photographed at high speed using a 35mm camera which incorporated the entire cell length in the field of view. The assembly can incorporate four cells in one flight.

For each experiment an electronics block diagram is provided. A control panel concept is given also for the surface tension induced convection. Both experiments are within the mid-deck locker weight and c-g limits.

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FOREWARD

This program was sponsored by NASA/Lewis Research Center. This study was conducted to transpose two sets of science requirements for fluids experiments into hardware concepts and preliminary design for mid-deck operation on the STS.

The major participants in the program were:

Liam Sarsfield	NASA/LeRC Program Manager
Jack Kropp	TRW Program Manager
Nahum Gat	Experiment Analysis
George Dosa	Design

Contributions were made by Talbot Jaeger and Chie Poom in electronics; Dale Waldo in Safety Analysis and James Zamel in Design.

ABSTRACT

Concepts for the operation of two fluid experiments in the mid-deck region of the STS were developed. Based upon these concepts a preliminary design for each experiment is made. The two experiments are the Surface Tension Induced Convection experiment and the Free Surface Phenomena Experiment. The mid-deck lockers of the STS are described and the requirements for operating an experiment in this region are described. For each locker the experiment design uses a two locker volume with an experiment unique structure as a housing.

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For each experiment an electronics block diagram is provided. A control panel concept is given also for the surface tension induced convection. Both experiments are within the mid-deck locker weight and c-g limits.

1. INTRODUCTION

Two experiments in Fluid Physics have been identified by NASA/LeRC for operation on STS. Each experiment is to be accommodated in the orbiter mid-deck locker region. Both experiments have a demonstrated potential for benefitting greatly from investigation at reduced gravity. During this program a concept of each experiment and preliminary drawings based upon that concept have been made.

The two experiments are:

1) Surface Tension Driven Convection in Reduced Gravity (Dr. S. Ostrach, Principal Investigator)

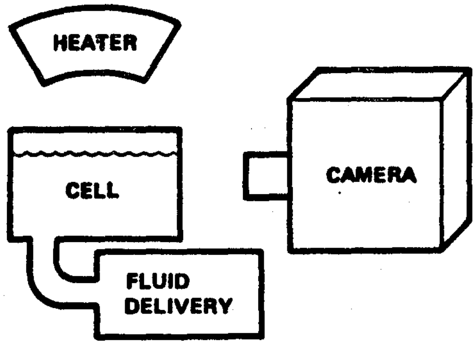
2) Free Surface Phenomena Under Reduced Gravity Conditions (Dr. Paul Concus, Principal Investigator)

Concepts and preliminary designs for each experiment have been developed specifically for mid-deck operation. In this development we:

- o use developed components in so far as possible.
- o utilize a simple design that will accomplish the science.
- o maintain performance compatible with mid-deck constraints.
- o minimize cost.
- o conform to PI requirements.

The objectives of each of these experiments are outlined in Figure 1-1a and 1-1b) together with a schematic for the performance of the experiment. Reference documents that establish experiment requirements and background are given in Table 1.1. Science requirements for each experiment were derived

A. Surface tensions driven convection in reduced gravity
Dr. Simon Ostrach - CASE - Western Reserve



Experiment Objectives

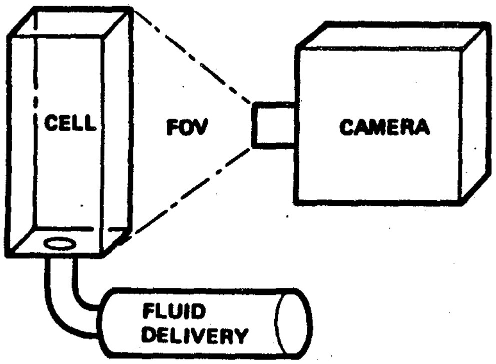
- Conduct experiment at reduced gravity that will study surface tension-driven flows
- Determine the free surface shape; temperature profile; velocity profile for transient and steady-state conditions
- To increase understanding of the effect of container geometry; and heat on fluid behavior associated with surface tension-driven convection

Method

- Fill a cylindrical cell with an inert fluid containing particles
- Heat the fluid surface symetrically from the top
- Record fluid motion by observing particle motion
- Monitor temperature

FIG. 1.1a) SURFACE TENSION INDUCED CONVECTION OBJECTIVES AND METHODS

B. Free surface phenomena under reduced gravity conditions
Dr. Paul Concus - University of California - Berkley



Experiment Objectives

- To photograph the nature of a liquid free surface under the conditions at reduced gravity
- To test the fluid behavior in trapezoidal vessels whose shape is dictated by theoretical analysis, thereby validating this theory
- To view the fluid configuration as a function of time as it flows into the vessel

Method

- To fill four trapezoidal vessels with fluid
- To photograph the fluid position within the vessel as a function of fill time

FIG. 1.1b) THE SURFACE PHENOMENA EXPERIMENT OBJECTIVES AND METHODS

and these are given in Tables 1.2 and 1.3. In addition to these requirements there are derived requirements that apply to each experiment subsystem. These requirements are contained in tables under the sub-system discussed.

In Sections 3 and 4 of this report the concept and design developed for each experiment respectively. Drawings of the major subsystems together with a list of instrumentation are presented.

Table 1.1

REFERENCE DOCUMENTS FDR SPACE SHUTTLE

FLUID PHYSICS EXPERIMENTS

1.1	Surface Tension Driven Convection in Reduced Gravity - Science Requirements (Dr. S. Ostrach, Dr. Y. Kamatoni) (Attachment to RFP 3-505994
1.2	Surface Tension Gradient Induced Flows at Reduced Gravity (S. Ostrach, June 1980) (NASA Contractor Report 159799 with Appendices).
1.3	Free Surface Phenomena Under Reduced Gravity Conditions - Science Requirements (Dr. P. Concus, Dr. R. Finn) (Attachment to RFP 3-505994)
1.4	Free Surface Phenomena Under Low and Zero-Gravity Conditions (D. Coles, P. Concus, R. Finn, L. Hesselink, June, 1981). (Phase II entry proposal with Appendices).

Table 1.2 SCIENCE REQUIREMENTS FOR THE SURFACE TENSION INDUCED CONVECTION EXPERIMENT

1. Experiment Container
   - o Circular Cylinder - 10 cm inside diameter
     - 5 cm deep
     - sharp lip located at the top edge to eliminate fluid creep
   - o Container made of transparent material to facilitate observation

2. Fluid Requirements
   - o Test fluid silicon oil (kinematic viscosity = 10 cs)
   - o Fill requirement - 395 ml ± 5%

3. Fluid Heating
   - o Supply heat such that a 50°F parabolic temperature distribution is established from center to edge
   - o Heater fixed in one position axisymmetric to the experiment container with fluid
   - o Experiment to be conducted at three heater powers; nominally heater will be on at one power for 20 minutes then switched to the next higher power.

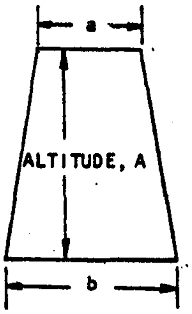
4. Experiment Operation Requirements
   - o Fluid to be quiescent at start
   - o Temperature - ambient
   - o Pressure - ambient

5. Diagnostics
   - o Temperature of fluid - measured a minimum of four places within the fluid bulk. Temperature accuracy ± 0.1°C
   - o Observation - visualization achieved by using particles in fluid
     - illumination of plane of fluid perpendicular to the camera
     - film time first three minutes and last three minutes at a given heater power
   - o Timing - lapsed time for each sum from heater on-recorded (on film)

TABLE 1.3 SCIENCE REQUIREMENTS FOR THE FREE SURFACE PHENOMENA EXPERIMENT

1. Experiment Container

   Container Dimensions - trapezoidal with relative dimensions as given



CYLINDER #	a (units)	b (units)	A (units)	AR
1	1.1	2	26	4:1
2	1.3	2	25	4:1
3	1.5	2	25	4:1
4	2.0	2	25	4:1

AR = ASPECT RATIO = HEIGHT/ALTITUDE

   - Overall height to be 100 cm
   - Interior finish to be "smooth"
   - Corners "sharp", without joints
   - Accommodate overflow
   - Container material/fluid must establish proper contact angle
   - Resolve fluid height

2. Fluid Requirements
   - Surface contact 58° ± 3° at 25°C with the container surface
   - Low evaporation rate
   - Fluid available to fill 4 containers to ¼ volume each
   - Slow flow rate to fill
   - Inflow to cover bottom - hold then re-start flow

3. Experiment Operations

   Temperature - Ambient
   - No thermal gradient along experiment container wall

   Pressure - 760 torr (Shuttle ambient)

   Experiment Number - Four

4. Diagnostics

   Thermal Management - to ° 0.1°C at 10, 20, 30 50, 70% of height
   - At center bottom (all thermal measurement requirements deleted at conceptual design)

5. Observation
   - View experiment along entire tube length from two angles
   - View from start of inflow through fill to ¼ volume

Using this data we have developed a schedule and rough order of magnitude (ROM) cost for each experiment through assembly and delivery. As specified in the original requirements we did not include integration in these costs. An estimate of the integration support is given.

Section 2 gives a description of the mid-deck accommodations for the experiments that are utilized in the present design.

2. MID-DECK EXPERIMENT ACCOMMODATIONS

This section summarizes the interface requirements and the design constraints for experiments that are accommodated in mid-deck. The number of lockers available for experiments in any flight will depend upon the number not required for crew use. The interfaces for experiments for mid-deck lockers are given in the following references:

2.1) Orbit Mid-Deck Payload Provisions Handbook Rev. B JSC-16536 (September 1982)

2.2) Orbiter Mid-Deck/Payload Standard Intefaces 30 Nov. '82. (JSC)

The experiments to be performed in the mid-deck will conform to volume, power and in crew involvement constraints. The operation in the mid-deck will allow crew intervention that is required for fluids experiment operation.

2.1 MID-DECK LOCKER ARRANGEMENTS

The mid-deck area of the STS system is shown in Figure 2.1-1a.

The location of the lockers within the mid-deck area is shown in Figure 2.1-1b. There are 33 locker spaces. An experiment can use the lockers themselves, or can utilize the volume of one or more lockers with an experiment peculiar structure built around it. A summary of the interfaces for each experiment in the mid-deck are given in Table 2.1-1 (Data abstracted from ref. 2.2). The important design parameters are highlighted below.

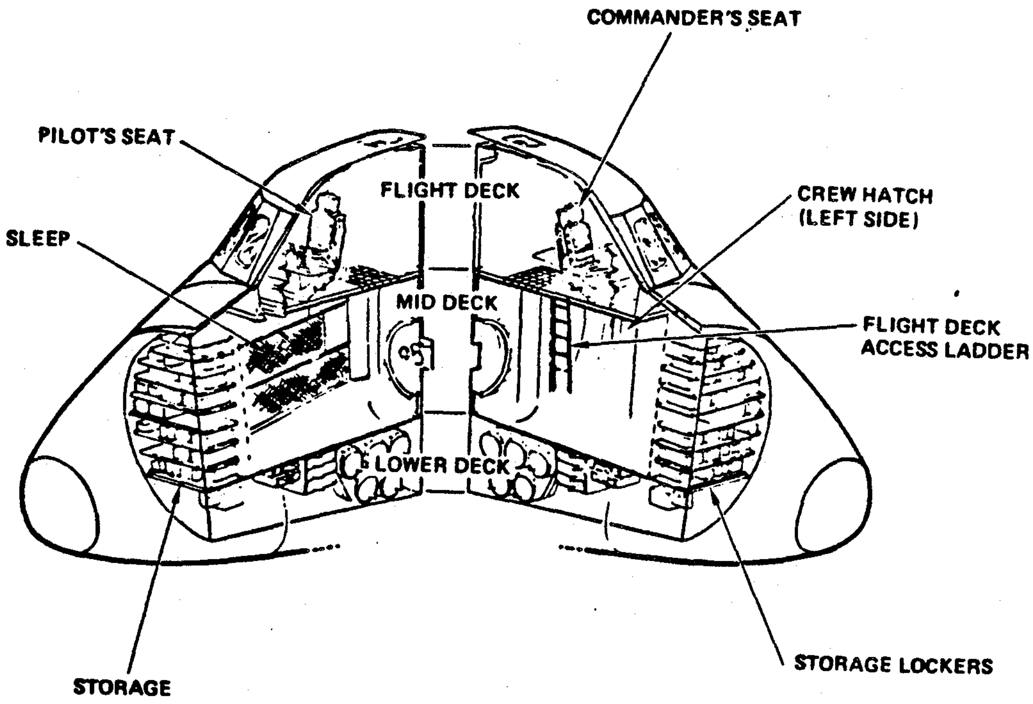


Figure 2.1-1a MID-DECK LOCATION IN THE SPACE SHUTTLE

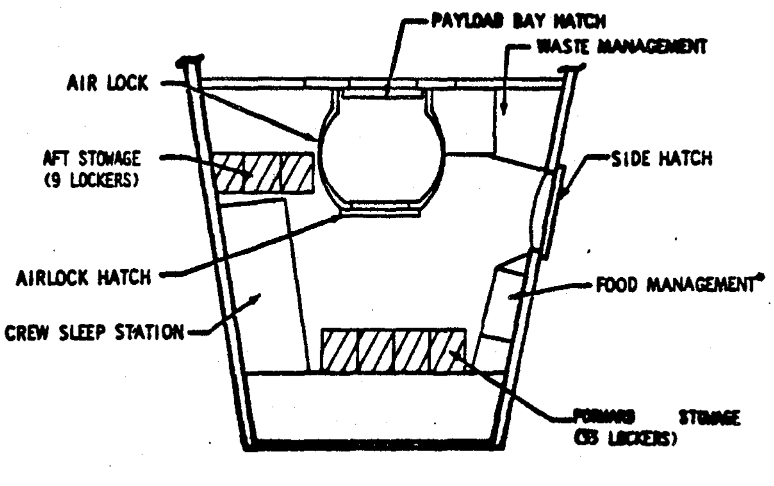


Figure 2.1-1b MID-DECK AREA ARRANGEMENT

Table 2.1-1

SHUTTLE MID-DECK ACCOMMODATIONS

I.	VOLUME	
	o Standard Locker Size	9.950" x 17.312" x 20.320" internal dimensions.
	o Standard Locker Volume	2.00 cubic feet
	o Optional Stowage Tray Sizes	
	o large	9.59" x 16.95" x 20.00"
	o small	4.64" x 16.95" x 20.00"
	o Single Adapter Plate Size	10.757" x 18.125" x 0.750"
	o Double Adapter Plate Size	18.125" x 21.882" x 0.875"
	o Maximum Total Payload Length	21.062" Including adapter plates
	o Maximum Total Payload Width and Breadth	May not extend beyond adapter plate perimeters.
II.	MASS	
	o Maximum Payload Mass	
	o Standard Locker	60 lbs. includings trays, etc.
	o Single Adapter Plate	69 lbs including plate, mounting hardware, etc.
	o Double Adapter Plate	120 lbs. including plates, etc.
	o Adapter Plate Mass	
	o Single	6.2 lbs.
	o Double	12.5 lbs.
	o Center of Mass Location	
	o Light, centered loads	< 14" from attachment face
	o Off-axis or near-maximum loads	< 10" from attachment face

Table 2.1 (cont.)

III. STRUCTURAL

o Steady-State Load Factors	
o along x-axis	-3.15 to + 1.22
o along y-axis	-0.80 to + 0.80
o along z-axis	-1.00 to + 2.50
o Load Factors for Critical or Potentially Hazardous Components	
o along x-axis	-3.3 to + 20.0
o along y-axis	-3.3 to + 3.3
o along z-axis	-4.4 to + 10.0
o Other Stresses	Random vibrational, acoustic, and transient stresses, as outlined in Interface Control Document.

IV. CABIN ENVIRONMENT

o Temperature	
o Normal	68-80 degrees F
o During ascent and reentry	< 95 F
o Air Pressure and Oxygen Content	
o Normal	14.7 PSIA, 25.9 % 02
o During EVA	10.2 PSIA, 31.0 % 02
o Emergencies	8.0 PSIA, 32.0 % 02
o Fixed Rate of Pressure Change	
o EVA Adjustment	2.0 PSIA/min
o Emergencies	9.0 PSIA/min

V. COOLING AND THERMAL

o Passive Cooling	Dissipate heat to mid-deck cabin air.
o Preferred method of Active Cooling	Fan or equivalent
o Maximum Waste heat Without Fan	
(Standard Storage Locker)	60 watts
(Experiment Specific Structure)	90 watts

Table 2.1 (cont.)

o	Active Cooling	Dissipates heat via water flow through connectors in mid-deck floor
o	Maximum System Coolant Pressure	
	o Normal	200 psig
	o Safety Factor	300 psig without leaks
o	Payload Surface Temperatures	
	o Surfaces Accessible to Crew	<113 degrees F
	o Other External Surfaces	<120 degrees F
o	Maximum Total Payload Waste Heat	
	o At 14.7 PSIA cabin air pressure	
	o Two man crew	650 W
	o Four man crew	375 W
	o At 10.2 PSIA cabin air pressure	
	o Two man crew	425 W
	o Four man crew	150 W

VI. <u>ELECTRICAL</u>

o	DC Power From Orbiter	
	o Mimimum Voltage	23 VDC
	o Maximum Voltage	32 VDC
	o Nominal Voltage	28 VDC, all at up to 10 amps.
o	Maximum DC Continuous Power at Min. Voltage	
	o Bus A	224 W
	o Bus B	215 W
	o Bus C	165 W
o	AC Power From Orbiter	
	o Frequency	400 Hz, 3 phase
	o Minimum Voltage	108 VAC
	o Maximum Voltage	120 VAC
	o Nominal Voltage	115 VAC, all up to 3 amps/phase
o	Connections	Done by crew. Two-wire cords for DC, four-wire cords for AC, with interfaces described in Orbiter specs

Table 2.1 (cont.)

o Electrical Bonding Requirements	RF circuits and electrical interfaces shall be electrically bonded to Orbiter structure.
o Electrostatic Discharges	Not permitted
o Alternating Magnetic Fields	< 130 dB above 1 picotesla (30 Hz to 2 kHz) falling 40 dB per decade to 50 kHz, at 1 meter away.
o Electrical Interface Noise	
o DC Power from Orbiter	
o Nominal Ripple	< 0.9 volts peak to peak narrowband (30 Hz to 7 kHz), falling to 0.28 volts at 70 kHz, remaining constant to 400MHz
o During Orbiter Hydraulic pump Start-Up (t < 300 msec)	Sawtooth ripple voltage, 4.0 volts peak-to-peak, 500 to 700 Hz, on the 28 VDC power bus.
o Transient Spikes	< 300 x 10-6 volt-seconds above or below line voltage. Peak spikes not to exceed +/- 50 volts from nominal bus voltage; rise and fall times < 56 volts/microsecond.
o AC Power From Orbiter	
o Nominal ripple	<1.5 volts rms narrowband (30 Hz to 1.5 kHz) , remaining constant to 400 MHz. Ripple shall not exceed 4% rms of the AC line voltage at inverter harmonic frequencies.
o Transient Spikes	Peak spikes not to exceed +/- 600 volts from nominal bus voltage; rise and fall times < 2.5 volts/ micro-second.

2.1.1 Structural/Volume

The payloads that utilize their own structure must mount to the wire trays of the mid-deck locker region using a single adapter plate 18.125 inches wide by 10.757 inches high; or through two single adapter plates to a double adapter plate 18.125 inches wide by 21.882 inches high. All hardware must extend no further than 20.32 inches from the wire trays including the adapter plates. Experiments usually occupy the space of one or two lockers. They must conform to the defined locker volume. The c.g. of the system is as defined in the Table 2.1-1.

2.1.2 Thermal/Environment

The thermal and the environmental interfaces in the mid-deck are given in Table 2.1-1. Pressure is as low as 10.2 PSIA during EVA activity. The oxygen partial pressure at 14.7 psi can be as high as 25.9%. Both factors will affect oxygen solubility in exposed liquids. The heat rejection by an experiment must be accommodated through coupling to the galley location fluid heat exchanger or through exchange to the cabin air. The fluid heat exchanger is available at the galley location and its use is not considered for the fluid experiments. The heat loss must be positively moved to the cabin air if it will be greater than 90W when an experiment specific structure is used.

2.1.3 Electrical/Power

The total power available to an experiment at a locker location other than the galley is 250 watts. If the power

requirements are greater than this the galley location must be used. The variation in DC power level is 23-32 volts which may require power supplies for equipment power stabilization.

2.2 APPROACH TO FLUID EXPERIMENT DESIGN

The approach used in developing the Fluid experiments in this study is diagrammed in Figure 2.2-1. For each experiment, the form and operation of the components within mid-deck were considered. In the presentation we have grouped the requirements, the concept and the preliminary design. These are discussed together in the appropriate section.

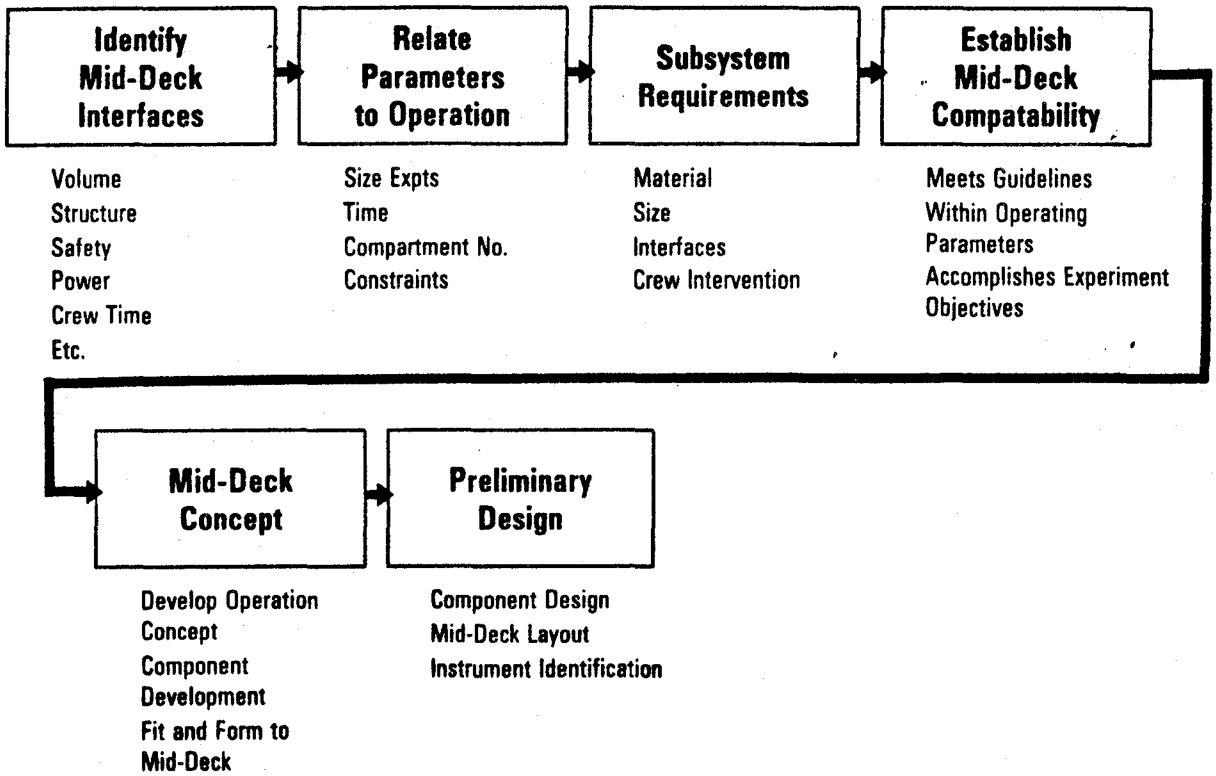


Figure 2.2-1 MID-DECK DEVELOPMENT THROUGH PRELIMINARY DESIGN

The experiment concepts were devised to be consistent with maintaining STS safety and achieving scientific objectives. The weight requirements and the c.g. requirements were estimated to insure that each of the experiments met these criteria. Each experiment was developed for two locker volumes using the standard double adapter plate. After completing the design we were made aware of a lighter weight plate and a method of attaching to them that will result in weight saving. This is discussed in Section 3.4 and 4.4.

3. SURFACE TENSION DRIVEN CONVECTION

The experiment concept meets the objectives shown in Figure 1-1a, and the science requirements of Table 1.2. The equipment function flow diagram for the experiment is described in Figure 3-1. This figure defines subsystems that must be addressed to accommodate experiment operation. The experiment description is grouped as follows. Section 3.1 describes the requirements, their conceptual implementation and the preliminary design drawings. The electronics requirements are contained in Section 3.2 while Section 3.3 describes experiment layout based upon this approach. The weight estimate is given in Section 3.4.

The nature of this effort was such that not all design issues could be resolved during the present effort. Section 3.6 gives design issues and lists some steps to accomplish their solution.

3.1 EXPERIMENT REQUIREMENTS, CONCEPT AND PRELIMINARY DESIGN

This section discusses the experiment requirements, and describes the implementation and the preliminary design of the experiment, its subsystems and components. The experiment can be described by the following subsystems:

a) experiment container

b) fluid storage and delivery

c) fluid heater

d) diagnostics; including temperature sensors, timing; illumination; flow visualization and data recording.

EQUIPMENT FUNCTION FLOW

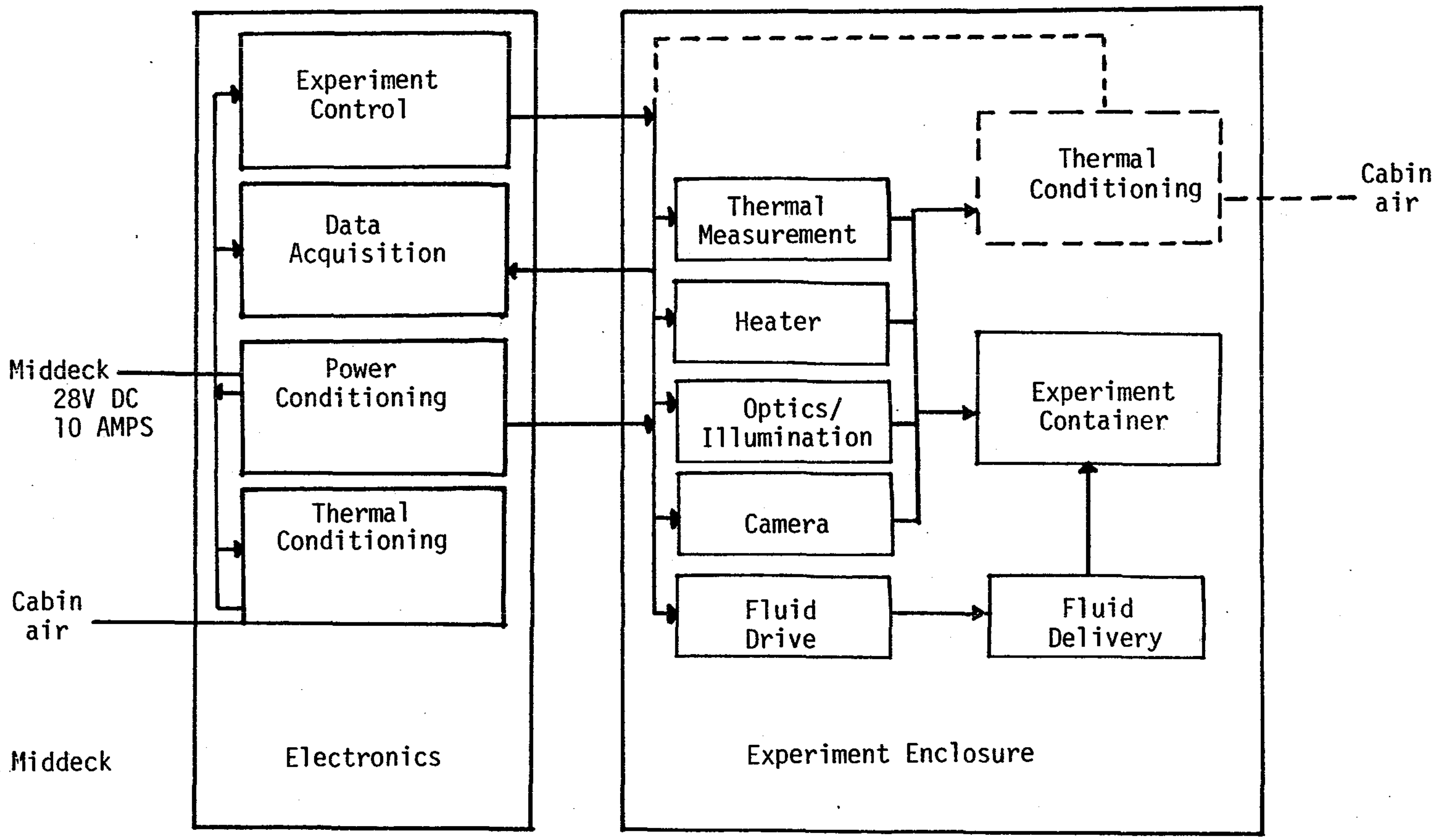


Figure 3-1 SURFACE TENSION DRIVEN CONVECTION EXPERIMENT FUNCTIONAL FLOW

e) thermal control (heat rejection)

f) electronics

The following functions are also considered in the analysis:

a) fluid type, including compatibility with STS environments.

b) experiment operations

3.1.1 Experiment Container

Table 3.1-1 details the requirements derived for the experiment container and their implementation. Figures 3.1-1 shows the design details of the container including the spill containment construction.

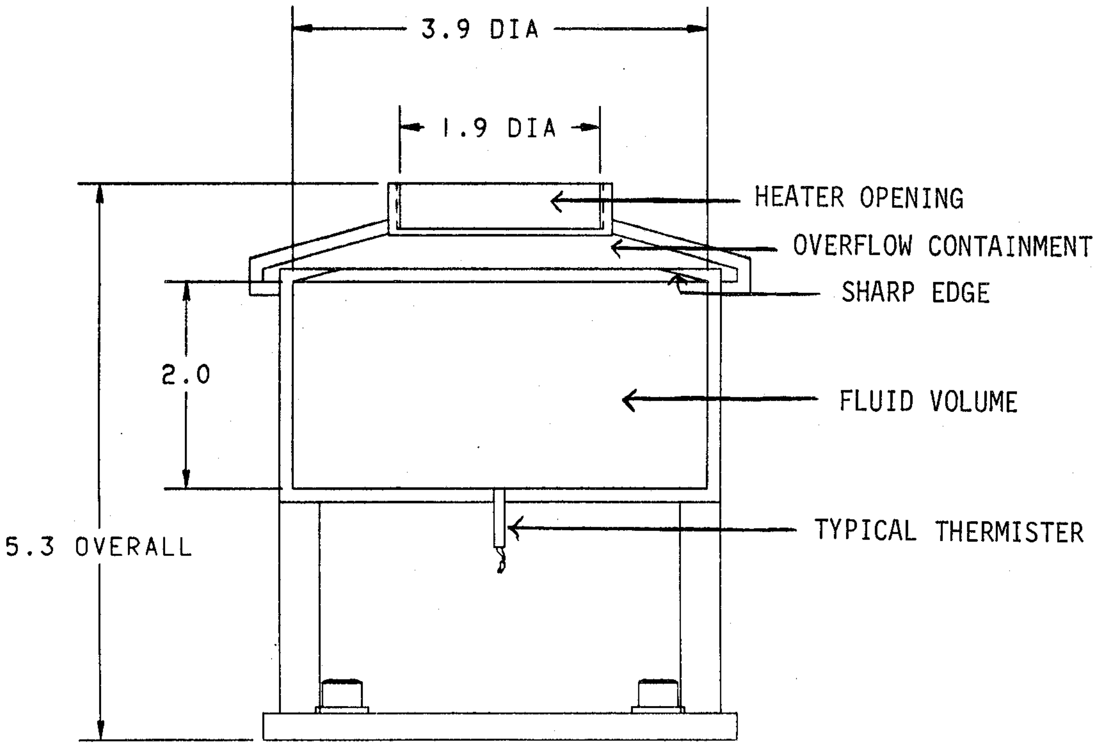


Fig. 3.1-1 SURFACE TENSION INDUCED CONVECTION EXPERIMENT CONTAINER

This consists of a trough on the container top with roof type protection cover. The fluid is fed to the container via a single port using 1/4" (0.635cm) line. This cross section is optimized compared to other cell dimensions to minimize influence on experiment operations. The fluid flow velocity is discussed in Section 3.1.2. The inner lip on the cell is a "sharp edge", designed to contain the fluid within the experiment volume and to establish the proper fluid surface characteristics. The overflow construction provides protection to contain liquid in the event of a spill from the container volume. The opening at the top of the vessel is designed to mate with the heater body. For this design embodiment, the experiment can be run only once. However, a growth option is to operate the experiment more than one time. Therefore, there is provision to remove the heater and replace it with a stopper. The stopper will contain the test fluid within the experiment container during reentry and landing. The provision for a stopper will also allow heater removal if it will be degraded by contact with the test fluid. Figure 3.1-2a shows atypical thermistor insertion method.

Figure 3.1-2b shows the PI's sketch of the container indicating the position of the thermistors. Four positions will be chosen for inclusion in the final design.

TABLE 3.1-1 EXPERIMENT CONTAINER REQUIREMENTS

REQUIREMENT	SOURCE/COMMENTS	IMPLEMENTATION
I-1 DIMENSIONS: CIRCULAR CYLINDER 10 CM ID 5 CM DEEP LIP ON TOP FOR CONTAINMENT	• PI REQUIREMENT IN RFP	• CYLINDER OF MATERIAL THAT MEETS STS REQUIREMENTS • PREFERABLY CLEAR POLYMER • COMPATIBLE WITH FLUID • POLYCARBONATE OR ACRYLIC
I-2 MATERIAL TRANSPARENT TO OBSERVATION ILLUMINATION	• PI REQUIREMENT IN RFP	
I-3 FOUR TEMPERATURE SENSORS	• PI REQUIREMENT IN RFP	• SEE 3.1.6
I-4 FILL EXPERIMENT CONTAINER WITH 395 CM^3 FLUID	• LOW "G" ENVIRONMENT	• USE 1 cm^2 ORIFICE • FLUID WILL CONTAIN PARTICLES
I-5 SPILL CONTAINMENT	• AVOID SPILLING ANY FLUID INTO THE EXPERIMENT ENCLOSURE (DERIVED REQUIREMENT)	• ENCLOSE EXPERIMENT CONTAINER TO TRAP ANY OVER-FLOW

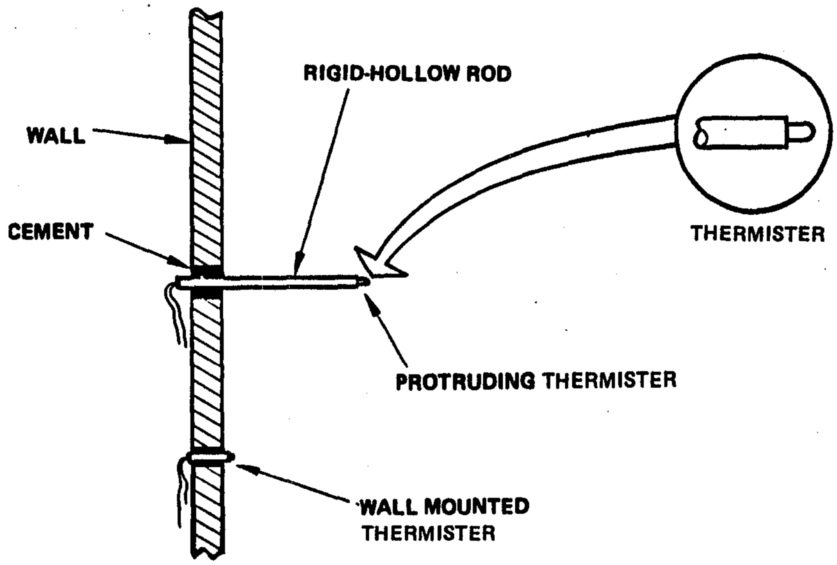


Figure 3.1-2a TYPICAL THERMISTOR INSERTION INTO EXPERIMENT CONTAINER

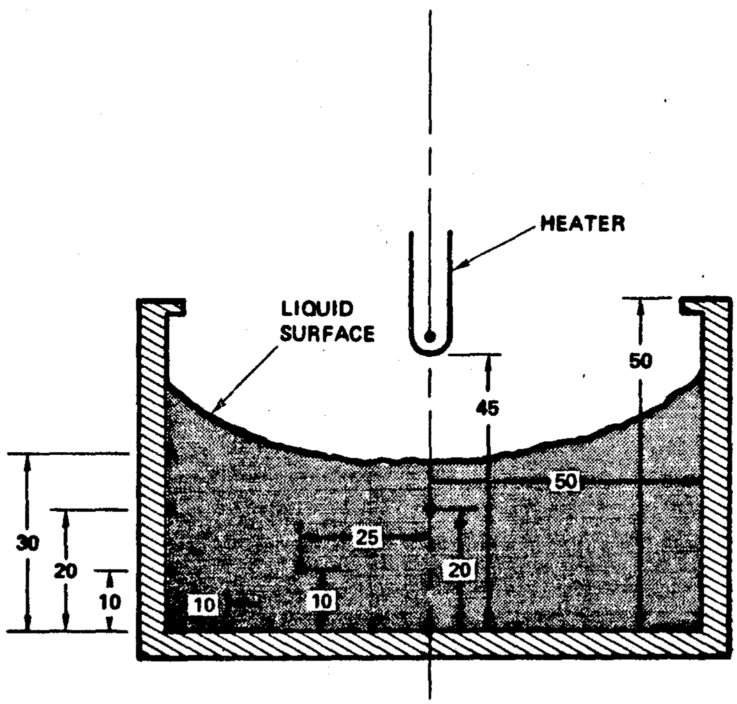


Figure 3.1-2b EXPERIMENT CONTAINER SHOWING THE POSITION OF THERMAL SENSORS

3.1.2 Fluid

Table 3.1-2 summarizes the requirements for the experiment fluid. The selection of a fluid is based upon the fluid properties and its compatability with the test cell material. Several fluids are appropriate for the experiment requirement and are compatible with the Shuttle environment. These fluids fall into two general categories; fluorocarbons such as Fluorinert (3M Company Electronic Liquids) and Silicone Fluids (Dow Corning Corporation or GE). The final selection can be made on a basis of a development evaluation in which the surface tension and the wetting angle of the liquids (with the selected test cell material) is measured for fluids of acceptable viscosities. Table 3.1-3 lists properties of several potential fluids. Particles are required for flow visualization and will be mixed with the fluid prior to loading into the experiment during pre-flight integration. A discussion of the methods used for particle dispersal and analysis of test fluids is contained in Appendix B. Appendix B also discusses the fluid properties further. The polydimethylgiloxane fluids have the required properties. There properties are listed under the Dow Coming 200 Series in Table 3.1-3.

3.1.3 Fluid Delivery

The fluid delivery requirements are given in Table 3.1-4. The critical requirement is to fill the experiment container to the sharp edge containment rim with fluid without voids. The fluid flow rate must be such that the integrity of the fluid mass is maintained during the filling process without bubbles or separation of parts of the fluid.

TABLE 3.1-2 FLUID REQUIREMENTS FOR SURFACE TENSION INDUCED CONVECTION EXPERIMENT

REQUIREMENT	SOURCE/COMMENTS	IMPLEMENTATION
II-1 SILICON OIL KINEMATIC VISCOSITY = 10 CP.	• PI SPECIFIED IN RFP	• AS REQUIREMENT STATES • LIST POTENTIAL FLUIDS
II-2 SUSPEND PARTICLES IN FLUID	• TO VIEW FLUID MOTION	• NUMBER DENSITY SIZE AND TYPE AND ACTUAL FLUID - SEE 3.1.6
II-3 INERT WITH LOW VAPOR PRESSURE	• SATISFY NASA-STS SAFETY REQUIREMENTS	• SILICON OIL SHOULD MEET REQUIREMENTS
II-4 COMPATIBLE WITH CONTAINER MATERIAL		• TEST FOR COMPATABILITY
II-5 SPECTRAL ABSORPTIVITY HIGH IN THE IR, LOW IN THE VISIBLE	• DERIVED REQUIREMENT FOR RADIATIVE HEATING AND FLOW VISUALIZATION	• PART OF FLUID SELECTION PROCESS BY TEST & ANALYSIS

Table 3.1-3 CANDIDATE FLUIDS FOR THE SURFACE TENSION INDUCED CONVECTION EXPERIMENT

FLUID	DOW CORNING 510 FLUID			550 FLUID PHENYL-METHYL SILICONE OIL	710 FLUID PHENYL-METHYL POLYSILOXANE	DOW CORNING 200 SILICONE FLUID		FLUORINERT (3M FLUID)	
	-50	-100	-500			10 cst.	20 cst.	FC-43	FC-70
SPECIFIC GRAVITY (@ 25°C)	0.985	0.992	0.992	1.07	1.11	0.935	0.949	1.88	1.94
KINEMATIC VISCOSITY IN CST									
AT 99°C	14	26	180	20	30	-----	-----	-----	-----
38°C	38	77	380	75	250	-----	-----	-----	-----
25°C	50	100	500	125	500	10	20	2.6	13.4
SURFACE TENSION DYNE/CM (25°C)	25	24.1	24.6	24.5	28.5	20.1	20.6	16	18
SPECIFIC HEAT CAL/GM/DEG. C	--	0.372	0.372	0.368	0.363	0.360	-----	0.25	0.25
FLASH POINT (°C)	--	--	--	308	302	210	246	BP 174°C	BP215°C
IGNITION TEMP (°C)	482	482	482	---	487	-----	-----	NON-COM-BUSTIBLE	NON-COM-BUSTIBLE
VOLUME EXPANSION @ 100°F				0.41993×10^{-3}	0.43×10^{-3}	-----	-----	1.2×10^{-3}	1.0×10^{-3}
COMMENTS	1) BLENDING IS POSSIBLE TO OBTAIN ANY DESIRED VISCOSITY 2) CLEAR FLUID			1) COLORLESS 2) VAPOR PRESSURE 0.08 TORR AT 443°F	1) COLORLESS 2) VAPOR PRESSURE 1.5 TORR @ 450°F	1) BLENDING IS POSSIBLE TO ACHIEVE DESIRED VISCOSITY 2) CLEAR FLUID		1) VAPOR PRESSURE 1.3 TORR @ 25°C 2) CAN BE BLENDED WITH FC-70	1) VAPOR PRES-SURE 0.1 TORR AT 25°C

Table 3.1-4 FLUID DELIVERY REQUIREMENTS

REQUIREMENT	SOURCE/COMMENTS	IMPLEMENTATION
III-1 FLUID VOLUME - DELIVERED VOLUME 395 CM^3 ± 5% (TO EXPERIMENT CONTAINER, PER EXPERIMENT)	• THIS FILLS THE CONTAINER TO 90% OF VOLUME	• DESIGN TO 1900 CM^3 CAPACITY • CAPABILITY TO FILL AT LEAST 3 CONTAINERS
III-2 FILL TIME TBD MINUTES III-3 FLOW RATE TBD CC/MIN	• NO PI REQUIREMENT • FLOW AT FIXED RATE • MAINTAIN FLUID ADHERENCE TO SURFACE • DEVELOP FILL APPROACH	• CYLINDER WITH POSITIVE DISPLACEMENT FEED • USE PNEUMATIC DRIVE FOR 1900 CC CYLINDER, THE REQUIRED DIMENSIONS IN CENTIMETER ARE: (see below)

OPTION	DIAMETER	LENGTH
1	10.0	24.0
2	15.0	10.75
3	20.0	6.0

The initial operating scenario for this experiment is that the cell be filled once for each STS flight. The filling method was selected to be manual using crew operation and involvement. During the design phase it was determined through discussions with NASA-JSC that there was a possibility of human error in the fill procedure. There is also the probability that in future missions the experiment may be run several times on a given missions. To enable several experiments to be run we determined the maximum size fluid storage container that could be incorporated into the mid deck arrangement. There is an existing 1900cc storage container that is available and that is flight qualified. This volume provides four fills of the current experiment container with approximately 20% excess. This storage vessel and the driver fit conveniently into the two locker mid-deck volume. Our concepts and designs are based upon the 1900cc volume. This does not compromise operation in any way and adds growth potential to the design.

The elements of the fluid delivery are:

(a) flow rate at low gravity

(b) fluid delivery device

(c) fluid flow driver

Flow Rate at Low Gravity

The appropriate fluid feed rate in low gravity is one which maintains a continuous stream without bubble and droplet formation. The maximum rate is determined by the force balance between fluid momentum and surface tension forces.

Figure 3.1-3 shows time required to fill a container as a function of entrance flow rate. At lower flow rates, the fluid will be less susceptible to flow breakup. Experiments are being performed at LeRC that will test fluid flow rates under reduced gravity. These tests will utilize a Lear Jet. When results are available they can be used to assist in evaluate final fluid flow values.

Several minutes will be required to fill the container. Lower flow rates will assure the appropriate fill characteristics.

Fluid Delivery Design

Two types of fluid delivery systems were evaluated.

1. A fluid storage vessel with the fluid moved by a piston driven by a dc motor drive or a stepper motor drive. The flow rate and total volume is controlled through the motor by elapsed time or the number of steps.

2. An accumulator method in which the fluid is driven by the expansion of compressed gas, either behind a piston or into bag which expands to drive the fluid out. Fluid flow rate is controlled by line sizing and the volume delivered is controlled by the on time of the driver gas.

The latter force maintains fluid cohesion and adherence to a surface of the test cell. A modified Weber number is derived in Appendix A which defines the criterion for meeting this condition. The modified We number must be less than four. If the We number <4 is maintained for the flow, the entrance velocity for silicon oil into the test cell is:

$$V < \sqrt{\frac{4\delta}{\rho d}} \sim 12\text{cm/sec}$$

Coupled with the 0.63cm diameter entrance port this determines a maximum feed rate into the cell of about 3.8 cm /sec. (less than 230 cm /min). Significantly Lower flow rates will be required to achieve the required fill properties. Therefore, capability to control the fluid flow rate rate is included in the design allowing for margins.

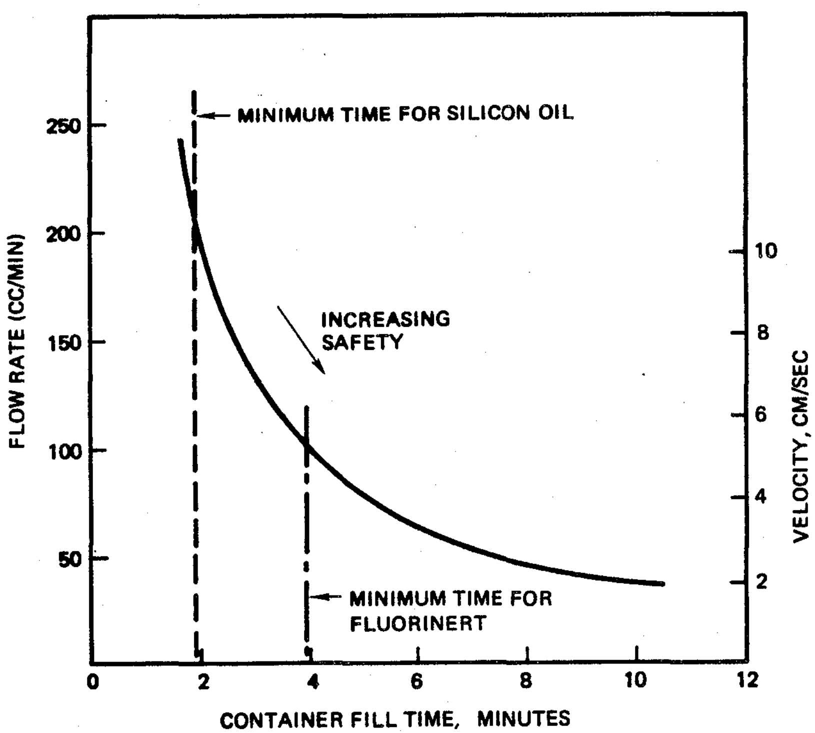


Fig. 3.1-3 FLUID DELIVERY TIME AS A FUNCTION OF FLOW RATE

Either method is suitable for this experiment. The accumulator concept is simpler and is adequate for the degree of control required. The stepper motor approach gives a more precise control of the fluid flow but it is more expensive. The precision stepper motor control is not required for this experiment. Space qualified accumulators with cylinder and piston arrangement are commercially available. The use of a shaped piston drive was compared to use of an expandable bag. Shaped piston drives are more reliable than an expandable bag. Therefore, a shaped piston drive was chosen.

Figure 3.1-4 shows the fluid delivery system design in the double locker structure. The fluid is stored in the accumulator. The large accumulator with a capacity to hold 1900 cc of fluid provides the capability to fill 3 to 4 experiment containers.

As discussed above, this volume is oversized for initial experiment operating concept. However, as figure 3.1-4 illustrates, the storage volume is readily accommodated. This will result in built-in added experiment flexibility without increase in complexity or significant cost impact. A lesser fluid storage capacity cannot reduce the number of locker spaces required. The two locker volume is controlled by the laser length (see section 3.1.6).

The accumulator is driven by pressurized gas. A stirrer with a motor is incorporated into the fluid end of the accumulator.

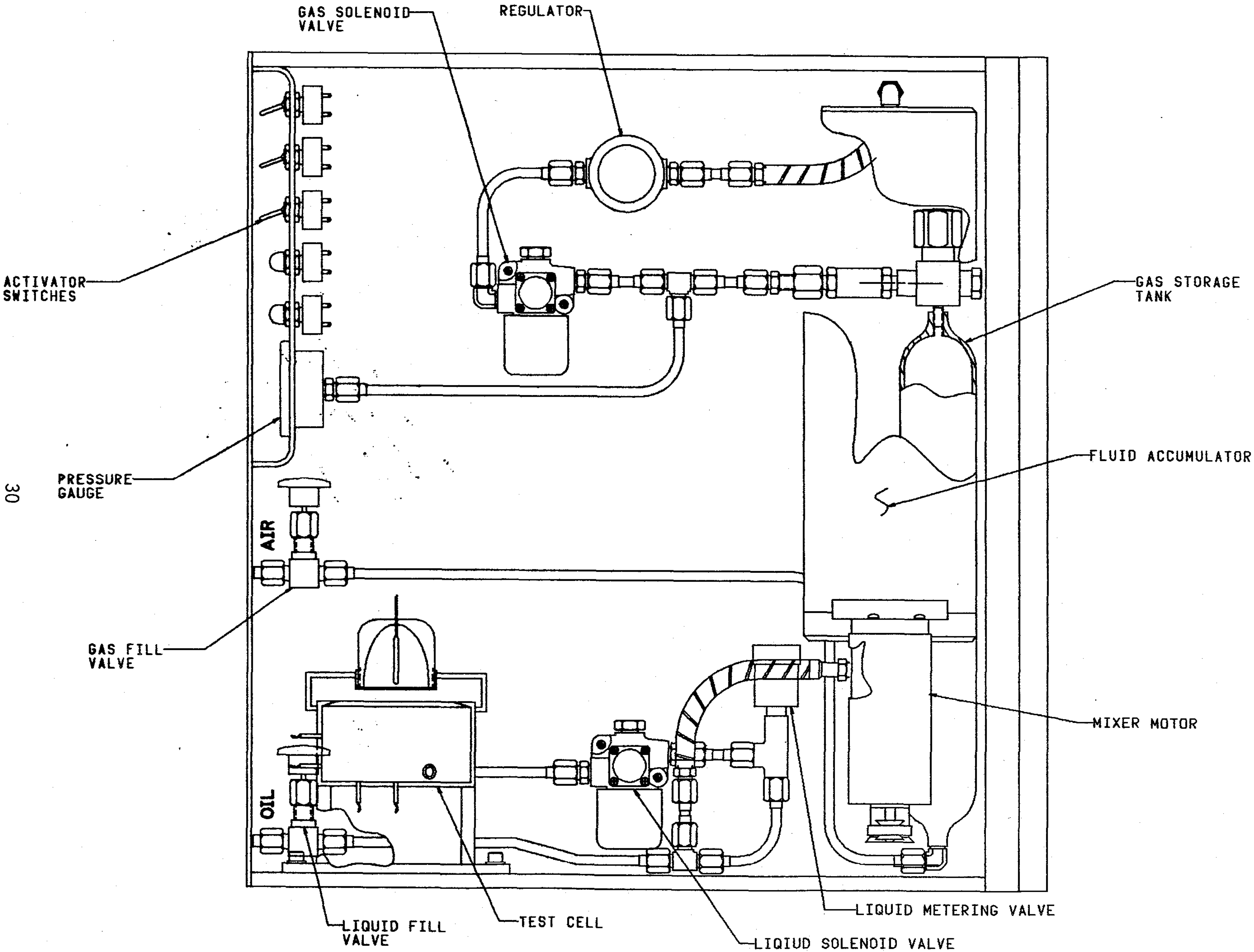


FIGURE 3.1-4: THE FLUID DELIVERY SYSTEM

The fluid from the accumulator is moved to the experiment container through standard lines fitted with a liquid metering valve. The driver gas interfaces to the piston end of the accumulator through a regulator which maintains constant pressure at the piston. There are two solenoid valves, one in the pressure line and the other in the liquid flow line. The two valves are used to give redundancy and to insure safe operation in STS environment. Provision is made to load the gas into the storage tank and the working fluid into the accumulator from outside the locker after experiment assembly. The same valve openings can be used to check the system during the integration cycle. The arrangement permits late filling if required.

The pressure regulator and the metering valve are preset at the operating values. They will not require adjustment during the experiment unless an inflight anomaly develops. The valves do have the capability for adjustment by a crewman if the initial flow rate requires correction. Such adjustment will allow for change in the flow rate if the flow levels determined pre-launch are not realized or are inappropriate.

The stirrer is used to mix the fluid containing particles for flow visualization. This insures uniform concentration. The particles will probably not be uniformly distributed at experiment initiation and the stirrer operation may require 5 to 10 minutes to insure the proper mixing. Particles so mixed will remain suspended at the low gravity levels expected.

The fluid flow will be initiated when stirrer operation ceases (or can begin with the stirrer still operating). When the solenoid values are opened, the compressed air drives the piston which in turn pushes the fluid into the experiment container. The flow rate is controlled by the metering valve.

Figure 3.1-5 shows the accumulator fitted with a stirrer assembly. A commercially available space-qualified accumulator with a fluid capacity of 1900cc is chosen. The stirrer assembly consists of a small propeller that is driven by a motor that is also commercially available. The stirrer and the motor unit are designed in such a way that will be retractable if it is contacted by the piston.

<u>Fluid Flow Driver</u>

Compressed gas is used to drive the fluid from the accumulator to the experiment container. The fluid flow rate must be controlled to meet the criteria set out above.

The pressure drop required to drive fluid from the accumulator to the experiment container is small because of the low flow velocities and is given by

$$\Delta P_f = f \frac{L}{D} \rho \frac{V^2}{g_c}$$

where

f = friction coefficient = 64/Re for laminar flow

L/D = length to diameter ratio

V = velocity

Re = Reynolds number

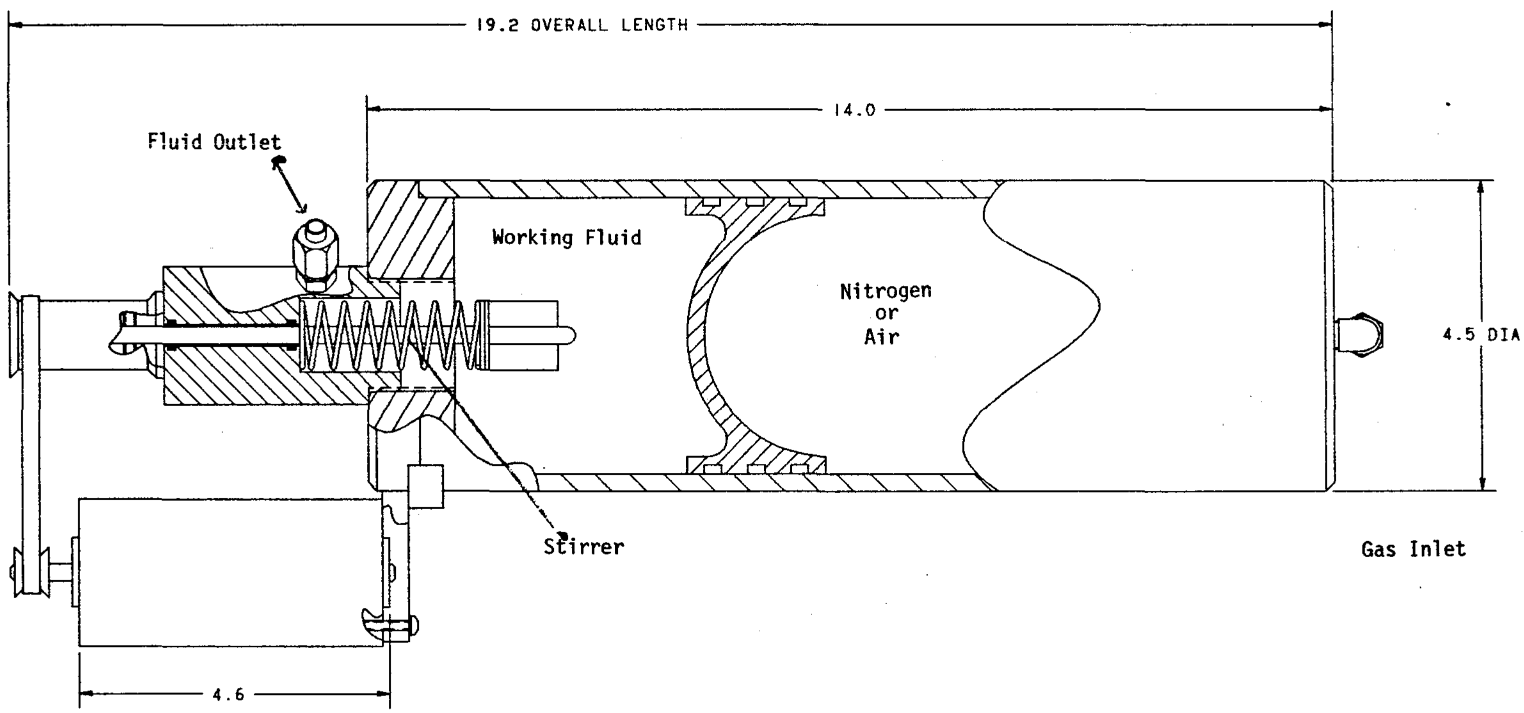


Fig. 3.1-5 THE ACCUMULATOR WITH THE PISTON DRIVE AND THE ATTACHED STIRRER.

A typical calculation of P_f is made using

$V = 10$ cm/s

$D = 0.635$ cm (for 1/4" flow line)

$L = 23$ cm

With the velocity and tube diameter and length chosen and with silicon oil as the fluid, the Reynolds number calculated is

$Re = 15.9$

which yields

$f = 64/Re = 4.025$

The pressure drop is

$$\Delta P_f = 1.21 \times 10^3 \text{ N/M}^2$$
$$= 9.1 \text{ torr} = 0.175 \text{ psi}$$

The required pressure differential across the piston in the accumulator will be defined by the specifications supplied with the accumulator or can be obtained by component tests. For sizing the gas storage tank, this pressure differential is assumed to be 3.5×10^3 N/M^2 (26 torr or 0.5 psi). Summing the pressure losses in the piping and values, and the pressure differential at the piston, the pressure of the gas (nitrogen or air) at the piston is around 6.9×10^3 N/M^2 (51 torr or 1 psi) higher than ambient pressure.

In determining the appropriate gas storage bottle volume we defined a volume, pressure and stored energy that would not require the qualification of the container as a pressure vessel.

A pressure vessel as defined in NHB 1700.7A is one in which

1) the stored energy is greater than 19 kj, or

2) has a pressure of greater than 100 psi, or

3) contains toxic or flammable gas.

Requirement 3 is met by using an inert gas nitrogen or air. A gas storage volume of 500cc was selected (Figure 3.1-6). The pressurant gas is stored at 6.8×10^5 N/M^2 (98 psi). This pressure is chosen to be below the design pressure which defines a pressure vessel (100 psi) for STS. The internal energy is given by:

$$\text{Internal energy,} \quad E = \frac{1}{\gamma - 1} RT$$

where

E = internal energy per unit mass

R = gas constant

T = absolute temperature

$\gamma = C_p / C_v = 1.4$

At 20 C:

$$E = 2.14 \times 10^5 \text{ joule/kg}$$

The mass of 500cc of nitrogen at 98 psi is 0.0038 Kg. Thus, the total stored energy is only 0.814 K joules. The gas storage container of 500 cc need not be treated as a pressure vessel in the design and will accomplish experiment objectives.

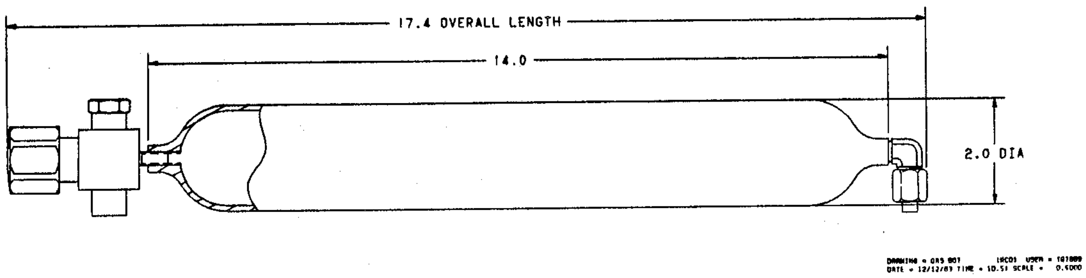


Fig. 3.1-6 THE GAS STORAGE TANK, VOLUME = 500cc

The operating requirement on the gas storage is that the final pressure remain greater than 7 psi above atmospheric when 1900 cc of nitrogen at 7×10^3 N/M^2 (1 psi) (.00232 Kg of nitrogen) is removed from it to drive the 1900 cc of fluid. In the present conditions, when 1900 cc of nitrogen is removed from the storage tank, the pressure falls from 98 psi to 39 psi. This pressure gives a satisfactory margin for performance. The regulator is selected to operate in this range of upstream pressures.

3.1.4 Fluid Heating

The requirements for the fluid heating are given in Table 3.1-5. Original requirements specified heater powers of 30, 60 and 100 watts. This was later amended to specify the desired temperature differential at the fluid surface (see Table 1.2). We have performed transient and steady state heat transfer analysis of heating of the experimental fluid in the container to determine the initial power requirements at the fluid surface. The model used gives the initial heat inputs at the fluid surface allowing the heat deposition to be determined. This initial heat disposition is important in the determination of heater sizing. In this analysis, the heat deposition was determined in the absence of fluid convection.

Table 3.1-5 FLUID HEATING REQUIREMENTS

REQUIREMENT	SOURCE/COMMENTS	IMPLEMENTATION
IV-1 SUPPLY HEAT SUCH THAT A 50°C PARABOLIC TEMPERATURE DISTRIBUTION IS ESTABLISHED FROM CENTER TO EDGE	• REQUIREMENT IN RFP	• TRANSIENT HEAT TRANSFER ANALYSIS INDICATE HEATER POWER REQUIREMENTS OF ONLY 3 TO 15 WATTS • EXPERIMENTS AT CASE WESTERN SHOW SIMILAR RESULTS • EVALUATE HEATER SOURCES • SELECT COMMERCIALLY AVAILABLE RESISTANCE WIRE HEATERS (CATALYST BED HEATERS)
IV-2 HEATER FIXED IN ONE POSITION AXISYMMETRIC TO EXPERIMENT CONTAINER WITH FLUID	• REQUIREMENT IN RFP	• ANALYSIS SHOWS HEATER START-UP TRANSIENT TIME TO BE VERY SMALL. FEW SECONDS FOR A WIRE ONLY. WITHIN A MINUTE FOR CATALYST BED HEATERS. • NO NEED TO BLOCK THE HEATER FROM FLUID DURING START-UP
IV-3 HEATER TO BE ADJUSTABLE WITH AT LEAST THREE POWERS AVAILABLE	• REQUIREMENT IN RFP	• MANUAL ADJUSTMENT TO THREE HEATER POWERS • FINAL POWER LEVELS TO BE BETWEEN 1-15 WATT

Such convection will of course be set up at the free surface and the flow measured as a part of he experimental observations. Two methods of heating the fluid were investigated. These methods were by lamp and by wire wound resistance heaters. Lamps with a strong

IR component can be readily directed and focussed, therefore they are attractive. However, radiant coupling to the fluid may be poor since in most cases a significant portion of the lamp's output is at shorter wavelengths. Heating with a heater element made of a resistance wire seems most promising. We have identified a space qualified catalyst bed heater that will satisfy the experiment requirements. The following sections detail these analyses.

3.1.4.1 Power Requirements

Analyses were performed to determine

1) the amount of heat that must be incident upon the surface to achieve the required temperature gradient.
2) the steady-state temperatures to be expected in the experiment container.

The time to achieve steady-state was not calculated. The initial analysis was made to determine the steady-state temperature conditions reached by the fluid in the cell. These conditions were calculated in the absence of heat loss at the cell wall.

This condition will be approximated at low gravity in the absence of convective cell wall cooling. The results of these calculations are given in figure 3.1-7 for three container radii. These results show that under these conditions energies of only a few watts (1-2 watts) was sufficient to raise fluid temperatures by 100 K or more at steady-state. The fourth graph illustrates that if the container interface has heat removed by convective cooling, 5-10 watts of heat at the center are adequate to develop the required thermal gradient.

These steady-state results show that the heat reaching the heater should be of the order of a few watts. The time required to reach steady-state temperature can be of the order of one or more hours.

The application of ten's of watts to a surface spot will initially overheat the heated area of fluid and boil it at the point of contact. Heat of a few watts at the surface is indicated. Work done at Case Western Reserve by Dr. Y. Kamotani and his student Tom Kessage show unshaped heater power of several watts is effective in initiating convective motion at earth gravity (Appendix B).

The transient temperature distributions are significant for this experiment especially the initial phases. Therefore we utilized a transient numerical model to determine the initial heat energy input requirements. The model inputs heat into given nodes and monitors the heat flow. The heat flow is modelled by conduction only.

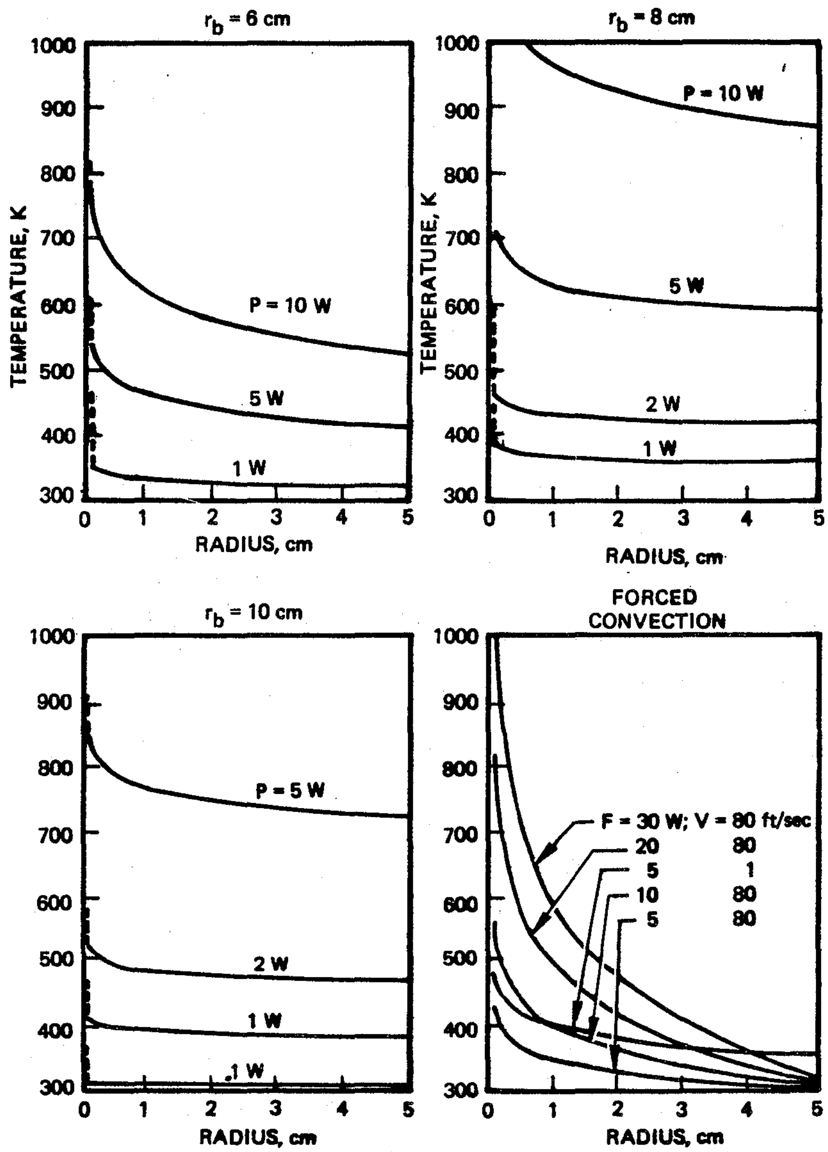


Figure 3.1-7 STEADY STATE TEMPERATURE OF FLUID IN CELL AS A FUNCTION OF THE CELL RADIUS FOR VARIOUS POWER LEVELS (r_b refers to the boundary radius at which boundary conditions at infinity are imposed)

Convection which will occur due to the free surface will moderate this flow. However, modelling below will give the initial heat input.

The transient heat transfer analysis of the fluid heat distribution by conduction is performed using the computer code SINDA (Systems Improved Numerical Differential Analyzer). This code can also solve heat transfer problems with multiple media. The experiment geometry is modeled using separate sets of nodes for the three involved regions, namely test liquid, container walls and surrounding air. The axisymmetric nodes used in solving the heat transfer problem are shown in Figure 3.1-8.

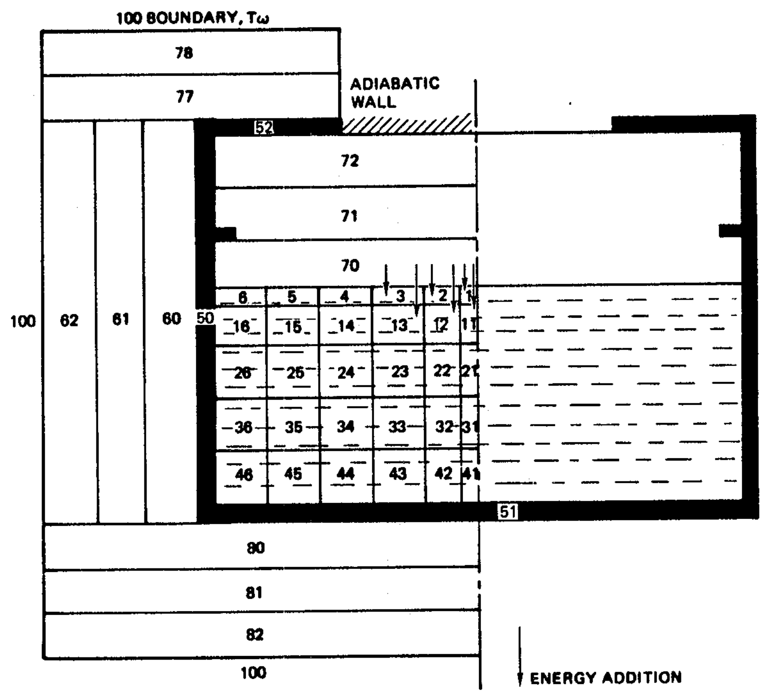


Fig. 3.1-8 MODEL OF HEAT ADDITION PROCERS TO EXPERIMENT CONTAINER (AXISYMMETRIC MODES USED IN SINDA CODE)

Using this model, energy addition can be made at any node. The heater is located axisymmetrically above the fluid and we simulated energy input from the heater to the experiment fluid by distributing the energy over the two top layers of the liquid in the proportion of 70% for the top layer (nodes 1-6) and 30% for the next layer (nodes 11-16) (see Figure 3.1-8). The energy is added only at the three inner nodes (1-3 and 11-13) to simulate the heater diameter. The distribution of the incident energy over these nodes is varied as part of the parametric analysis. In this way the initial energy distribution is approximated and the energy level that is required can be defined. This information used to size the heater.

Figures 3.1-9 and 3.1-10 show the radial temperature distributions at the liquid interface and at other axial depths as a function of the fluid radii. Figure 3.1-9 shows the radial temperature distributions at 20 and 40 minutes after energy addition of 1 watt. Since 70% of the energy in this case is added to the small inner most node, its temperature increases sharply as seen in the figure. This heating pattern is relatively independent of time especially at the center. The diffusion of heat energy in radial and axial direction from conduction is low. The variations in radial temperature distributions over an interval of 20 minutes is small. The temperature difference from center to edge of the liquid interface is around 80 ^{o}C. This exceeds the requirement of 50 C (See Table 1.2).

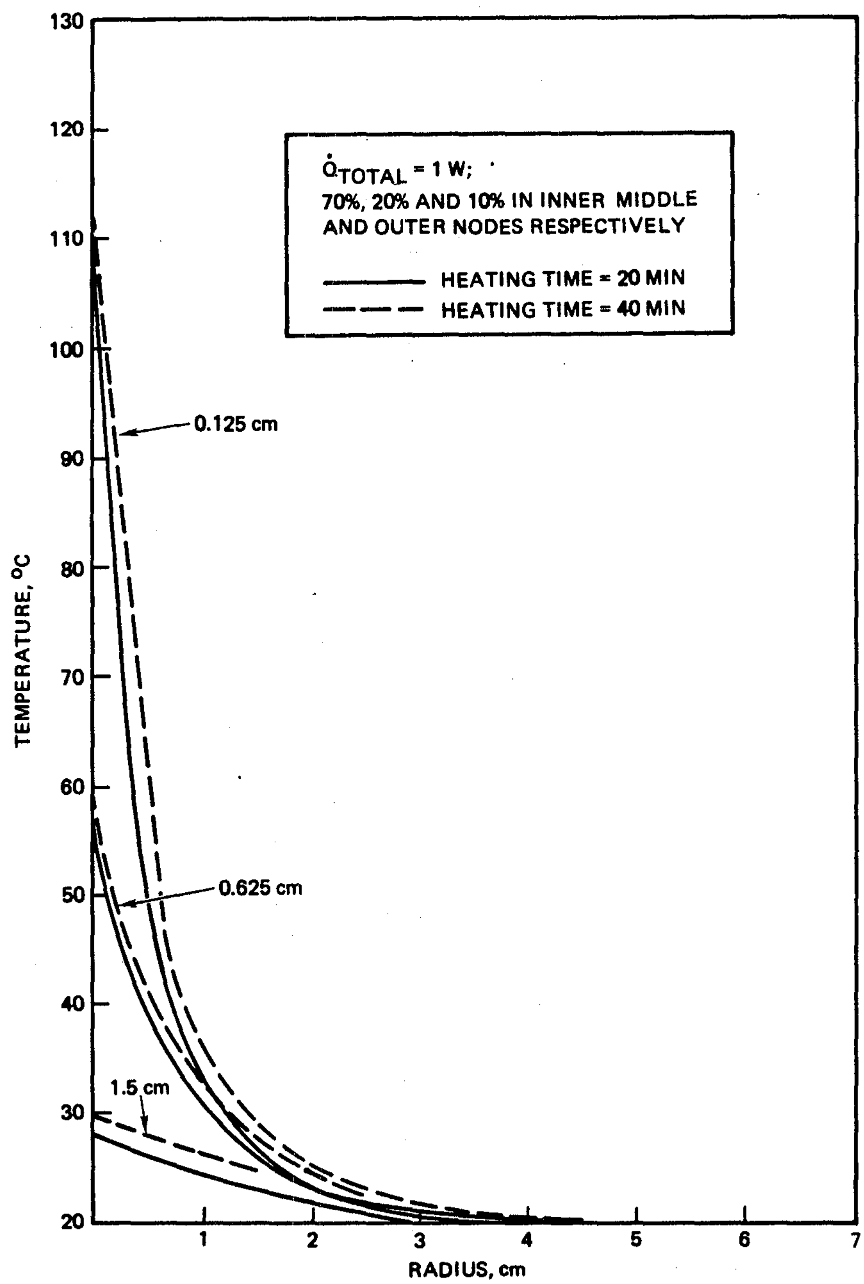


Figure 3.1-9 RADIAL TEMPERATURE DISTRIBUTIONS AT 1 WATT ENERGY INPUT FOR DIFFERENT DEPTHS

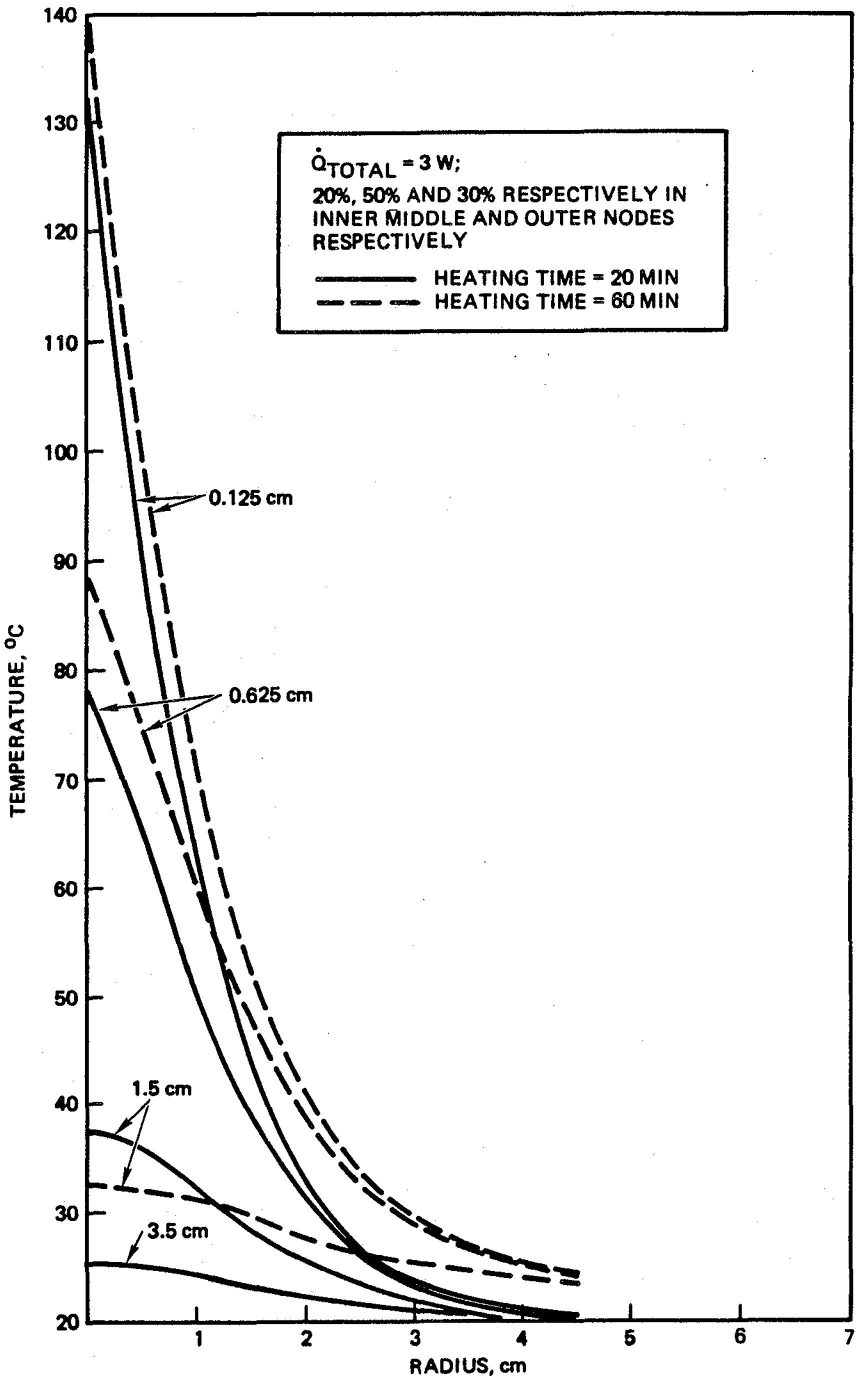


Fig. 3. 1-10 RADIAL TEMPERATURE DISTRIBUTIONS AT VARIOUS FLUID DEPTHS.

Figure 3.1-10 shows the radial temperature distributions at 20 and 60 minutes during energy addition of 3 watts. Here the energy added was modelled to be more evenly spread out over the three inner nodes. This gives the wider peak in the temperature distribution. In this case the temperature difference from center to edge at the liquid interface is around 90^{o} C. The initial energy is concentrated near the center and develops the required temperature difference. The initial heater deposition at the center is required to be only one watt in a one cm diameter circle to generate at least a 50^{o} c differential from center to edge.

The temperature distributions shown in Figures 3.1-9 and 3.1-10 indicate that energy additions at a rate of 1 to 3 watts is sufficient to obtain the required temperature difference of 20 to 50^{o} C between the center and the edges. The calculations used water as a model fluid but the heat absorption characteristics of silicone oil or fluorinert are expected to be similar. In an efficiently designed heater about 30 to 40% of incident radiation will be absorbed. In addition, there will be other losses at the heater so that not all the radiation emitted by the heater is incident on the liquid. The overall efficiency will be 20-30% and a heater of 3 to 15 watts power output is required. Table 3.1-6 summarizes the heater power requirements using a heater with 208 ohms resistance.

Power Dissipation at the heater resistance	3 Watts	6 W	10 W	15 W
Voltage drop required across the 208 Ω resistor	25 Volts	35 V	46 V	56 V
Radiant energy incident on liquid per second (power)	2.4 Watts	4.8 W	8.0 W	12.0 W
Energy absorbed by liquid (water) per second (power)	0.82 Watts	1.63 W	2.7 W	4.1 W

Table 3.1-6. HEATER POWER REQUIREMENTS, HEATER RESISTANCE = 208 OHMS

3.1.4.2 Review of Heat Sources

The analysis above translates in a requirement for a heat source capable of delivering from 1 to 20 watts. The source must meet the safety and flight qualifications required for STS operation. Another requirement is that the energy be transferred to the fluid and that a variable energy output of known power be available. The heater levels that were determined using the modelling techniques above are similar to those that were determined to be effective experimentally by Dr. Kamotani (Appendix B). In his work heater powers of 6-20 watts were used to obtain flow data under terrestrial conditions.

These heaters were simple wire coils without reflectors and therefore ly inefficient. These results do verify that a heater power range of up to 20 watts by analysis has to be verified through initial experiments.

3.1.4.3 Heat Coupling to Test Liquid

Flow visualization requirements dictate that the fluid be transparent in the visible range. The spectral absorptivity of the liquid or the spectral extinction must be known in order to determine whether the heat is deposited near the surface. The heat source spectrum must match this spectral absorptivity. We considered both lamps (radiant) and wound wire heaters. The following is a brief summary of lamps available as heat sources.

3.1.4.4 Lamps as a Heat Source

We discussed the use of lamps as heat sources with several potential manufacturers. The following is a summary of our contacts.

- Medtherm Corp., Huntsville, AL. (205)837-2000 manufactures IR heaters, quartze lamps enclosed within an elliptical reflector. The lamps are in a linear array; up to 500 watts with an efficiency of 60-75%. Water cooling is sometimes required. No flight qualified lamps available or circular symmetric lamps are available.

- Oriel Corporation, Stanford, Conn., (203)357-1600 produce quartz-halogen (tungsten) lamps and mercury, up to 1000 watts in power. The tungsten filament lmap has a gray body type radiant spectrum, all other lamps produce output in the visible and UV. None of these lamps are suitable for the experiment.

- Optical Radiation Corp., Azusa, Ca., (213)969-3344 makes compact xenon and mercury-xenon arc lamps, which come in various rating and packed in a reflector which focuses the beam to a small spot. A typical xenon lamp has output as follows: 4.4% from 0.2 to 0.38 . The lamps have the same problems as those of Oriel.

- ILC Technology, Sunnyvale, CA., (408)745-7900. produce compact xenon illuminators (33 mm diameter, 40.4 mm long - 300 watt device) which are very efficient. They produce the flood lights (800 watts short arc lamp) used in the Shuttle's payload bay. They do have the experience for space flight and are the most promising contact. (They also mentioned a substitute for a fluorescent lamp for the Shuttle crew compartment).

- Other sources that can be considered are:
  - Radiant spot heaters for desoldering
  - Sources in vaporization spectrophotometers

3.1.4.5 Resistance Wire Heating

A wound wire heater is formed by wrapping wire about a central core or by a large coiled loop. The electrical power (P) dissipated by the wire alone is related to the voltage (V) and resistance (R) by

$$P = V^2/R \qquad 3.2$$

where

$R = \rho\ (L/S)$

ρ = resistivity or specific resistance

L = length of wire

S = cross section

The heat dissipated by radiation is

$$p = \epsilon \delta T^4 A_L \qquad 3.3$$

where:

A_L is πDL

ϵ is the emissivity

δ is the Stefan - Boltzman constant

T is the absolute temperature.

A typical wire heater uses nichrome wire. For this wire the properties are:

ρ = 650 ohm - circ mil/ft.

ϵ = 0.6

$\delta = 5.73 \times 10^{-6}$ watt/in^2 K^4

Table 3.1 - 7

NICHROME WIRE REQUIREMENTS FOR SURFACE TENSION INDUCED CONVECTION EXPERIMENT

GAGE #	WIRE DIAMETER (cm)	LENGTH (cm)	RESISTANCE (ohm)	VOLTAGE REQUIRED FOR POWER = 3W T = 1100°K	POWER = 15W T = 1645°K
24	5.1×10^{-2}	3.74	0.227	0.83 volts	1.84 volts
30	2.6×10^{-2}	7.3	1.79	2.3 V	5.26 V
34	1.6×10^{-2}	12.0	7.4	4.7 V	10.5 V

Table 3.1-7 gives the required length of wire and the required voltages for power dissipation of 15 watts and 3 watts. The nichrome wire length is chosen such that temperature of 1100 ^{o}K at 3 watts power and 1645 ^{o}K at 15 watts power, are maintained.

The analysis above considers the heater requirements with reference only to a suspended coiled wire and was derived to determine the wire wound heater design parameters. These indicate that a wire wound heater can be designed that allows the heater conditions to be met. The wire wound heater is a preferred approach and will satisfy the experiment requirements. The heater design will require development into a structural unit.

We have identified an available space qualified heater which meets the requirement to supply up to 20 watts of power. This is a catalyst bed heater that is used in TRW satellite programs and is well tested and space qualified. Figure 3.1-11 shows the design of the heater that can be modified to meet our requirements. The heater is available at resistances 208, 257 and 273 ohms, and operates on both 110 Vac or 28V DC voltages. With the 208 ohms resistance heater, the heater power dissipation of 3 to 15 watts can be obtained with voltage drops across the heater of 25 to 56 volts. This heater will satisfy all requirements when used with an efficiently designed reflector.

A critical parameter is the time for the heater to reach steady-state temperature. The transient analysis of the wire heater shows that the heat-up time for a suspended wire is 6-7 seconds. An actual heater has other support structures which increase the thermal mass of the heater system. For the catalyst bed heater chosen in this design the support structure consisting of insulation, inconel housing and lead wires increases the thermal mass of the heater by an order of magnitude. This in turn increases the time to reach a steady temperature to one minute. The duration of the surface tension experiment is 40 minutes and longer. The heater start-up transient is small compared to experiment time and it is not expected to appreciably effect fluid motion measurements.

3.1.4.6 Heater Design

The catalyst bed heater chosen for the surface tension experiment (Figure 3.1-11) is 1.25 inches long and 0.125 inch in diameter.

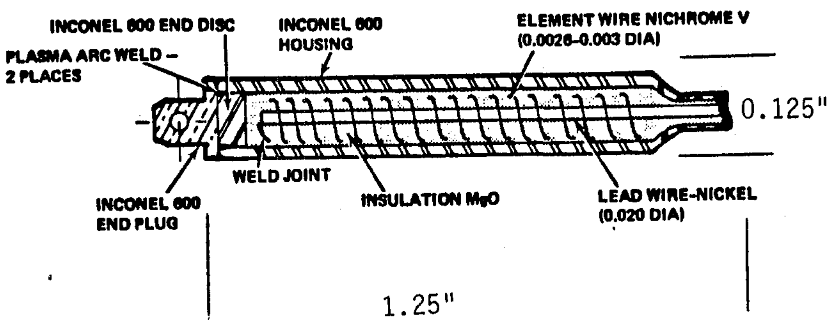


Figure 3.1-11. SPACE QUALIFIED CATALYST BED HEATER FOR SURFACE TENSION INDUCED CONVECTION EXPERIMENT

The heater must radiate symmetrically on a small surface area, use a minimum of power, and maximize radial temperature gradient across the liquid surface. To shape the heat at the fluid surface, a parabolic reflector is required. The reflector must be designefd to conform to required heat distribution as defined for the experiment practical.

Figure 3.1-12 shows the experiment container with the heater of figure 3.1-11 mounted vertically over the liquid surface. The heater is mounted rigidly to the reflector and isolated from the reflector structure. The parabolic reflector is placed around the heater to concentrate the reflected radiation to an area at the center of the liquid surface. The design of the reflector will determine the initial heat distribution across the cell. The modelling considered 70% of the heat to be put into a 0.5cm diameter area at the center of the fluid surface. The reflector design will be dependent upon the required heat distribution. Further analysis must be performed during the detailed design phase to finalize the reflector configuration.

3.1.5 Experiment Operation

The requirements that must be maintained during experiment operation are listed in Table 3.1-8. The experiment operation requires the gravity be maintained at a low steady level with no perturbations during the experiment. The experiment fluid must be within a temperataure range that maintains vapor pressure compatable with the STS atmosphere purity.

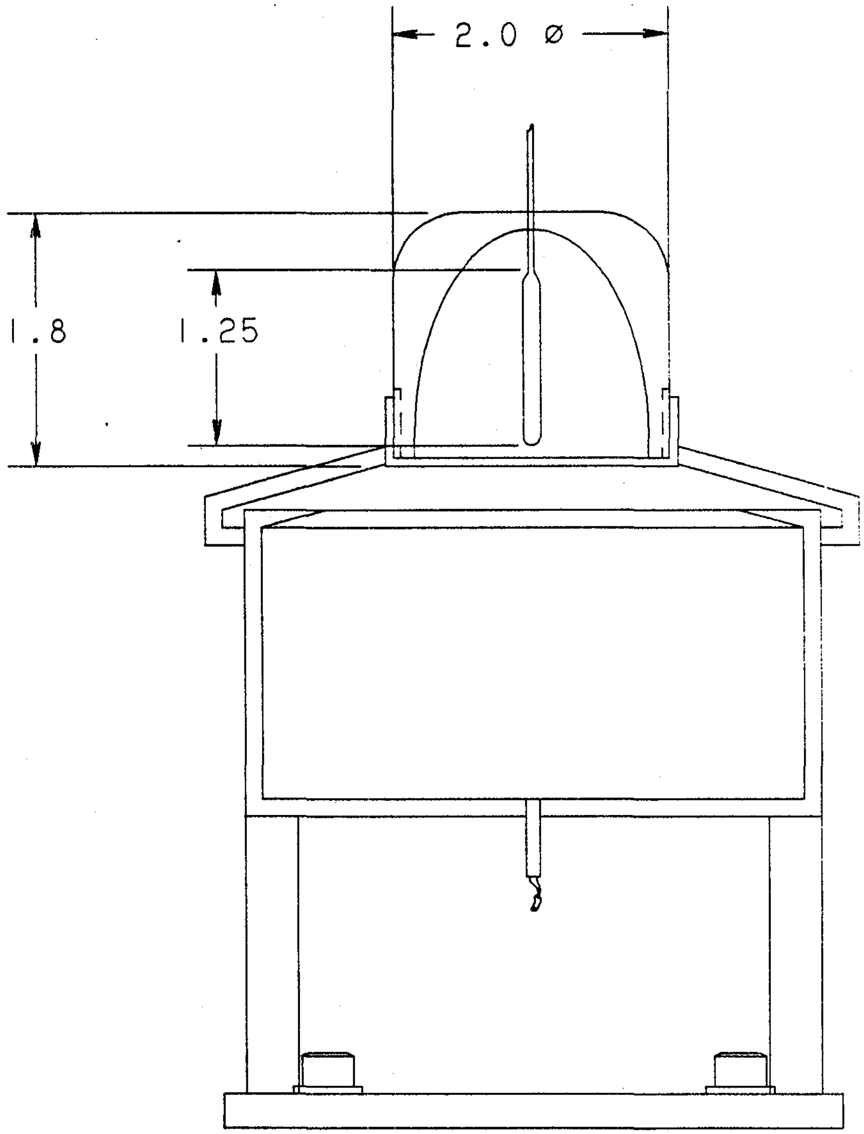


Figure 3.1-12. THE HEATER MOUNTED ON TO THE EXPERIMENT CONTAINER

Table 3.1-8 EXPERIMENT OPERATION REQUIREMENTS

REQUIREMENT	SOURCE/COMMENTS	IMPLEMENTATION
V-1 TEMPERATURE - AMBIENT PRESSURE - AMBIENT	• PI REQUIREMENT IN RFP	• NO ACTIVE CONTROL • NO SENSOR
V-2 FLUID STORAGE TEMPERATURE $25 \pm 5°C$	• DERIVED REQUIREMENT	• NO ACTIVE CONTROL OF FLUID TEMPERATURE
V-3 • G - LEVEL < 10^{-5} • AC FLUCTUATIONS IN G-LEVEL DURING EXPERIMENT	• PI REQUIREMENT IN RFP • BOND NUMBER IS $B_o = \frac{\rho G R^2}{\sigma} < 0.8$ THUS ACTUAL G LEVEL DEPENDS ON FLUID PROPERTIES	• ESTABLISHED BY STS ORBITS AND ACTIVITIES
V-4 INITIAL CONTAINER TEMPERATURE AMBIENT		• UNCONTROLLED
V-5 MAXIMUM ALLOWABLE FLUID TEMPERATURE < TBD	• SAFETY REQUIREMENT TO NEGATE ANY BOIL-OFF	• INTERLOCK FLUID TEMPERATURE AND HEATER OPERATION TO SHUT-OFF HEATER AT TBD = T (FLUID)
V-6 TOTAL EXPERIMENT VOLUME INCLUDING HARDWARE AND DIAGNOSTICS - IN TWO LOCKERS	A MINIMUM CAMERA-TO-OBJECT DISTANCE DETERMINES EXPERIMENT VOLUME	• ANALYZE WEIGHT AND VOLUME FOR COMPATABILITY

TABLE 3.1-9. DIAGNOSTICS REQUIREMENTS

REQUIREMENT	SOURCE/COMMENTS	IMPLEMENTATION
VI-1 THERMOCOUPLES - 4 REQUIRED	• PI REQUIREMENT IN RFP • RECORD DURING EXPERIMENT	• RANGE 10°C - 100°C CALIB/ PRECISION/ACCURACY EACH 0.5°C
VI-3 POWER TO HEATER		• MONITOR TO ± 10%
VI-4 ILLUMINATION	• SHEET OF LIGHT IN A MERIDIONAL PLANE OF CYLINDER • CONSIDER INTERNAL LASER COOLING REQUIREMENTS	o He/Ne LASER (5 MW)
VI-5 VISUAL DATA VIEWING TIME - 15 MINUTES with 1 HOUR CAPABILITY	• PI REQUIREMENTS IN RFP • FRAME RATE: 1 FPS	• CINE CAMERA • 200 FT CASSETTE REQUIRED
VI-6 DATA RATE 0.1/SEC	• SINCE TEMPERATURE AND HEATER POWER ARE TO BE MONITORED THE TEST, THE OPTIONS FOR DATA ACQUISITION ARE (a) DUAL IMAGE SPLIT FILM, AND (b) TAPE RECORDER	• TAPE RECORDER REQUIRED TO ACCEPT ACCELEROMETER DATA
VI-7 TIMING ± 1 SEC		• TAGGED TO CAMERA OPERATION

In the event of heater overvoltage an automatic shut-off can be coupled to a thermistor to power down the experiment to prevent a runaway situation.

3.1.6 Diagnostic Instrumentation

Table 3.1-9 gives requirements for experiment diagnostics.

The specific diagnostics required are:

1. Thermal sensors.
2. Flow visualization and data recording
3. Timing

The implementation of these diagnostics, and data rates required are discussed in the following sections.

3.1.6.1 Flow Visualization

The experiment requires that the surface tension induced flow be visually determined and recorded. The objective can be met by mixing particles in the fluid and illuminating them with a laser and photographically recording the light scattered by the particles at 90 degrees from the beam.

The suspended particles must have the following properties:

- They should be small enough that they are carried with the fluid flow and do not suffer drag nor distort the flow.

- On the other hand, they should be as large as possible to enhance observation.

- o The specific gravity of particle should be such that it will not settle in the selected fluid at the gravity levels expected.

The number density of the particles must be low enough to allow observation of discrete events on film and to minimize secondary scattering. But, the number density must be high enough to produce sufficient scattered light intensity for recording. A study of particle and fluid properties relevant to the visualization of surface tension driven convective flow was conducted by Y. Kamotani and T. Kerslake at Case Western Reserve University (1983). Results of tests by these authors indicate that 1μ alpha alumina particles in a concentration range of 3.0-7.0 mg per liter give adequate flow visualization (see Appendix B).

3.1.6.2 Optical Recording

Optical Train. The optical train is shown in figure 3.1-13. The light source chosen is a 5 mW HeNe laser, which is the highest power laser that can be accommodated within the experiment volume of a double locker. A 20 mW HeNe laser of similar design is already qualified for Spacelab use. The laser chosen can probably be qualified by similarity to the larger laser. The HeNe laser emits at 633nm, in the red. The light intensity should be maximized since the following analysis suggests the system may be intensity limited.

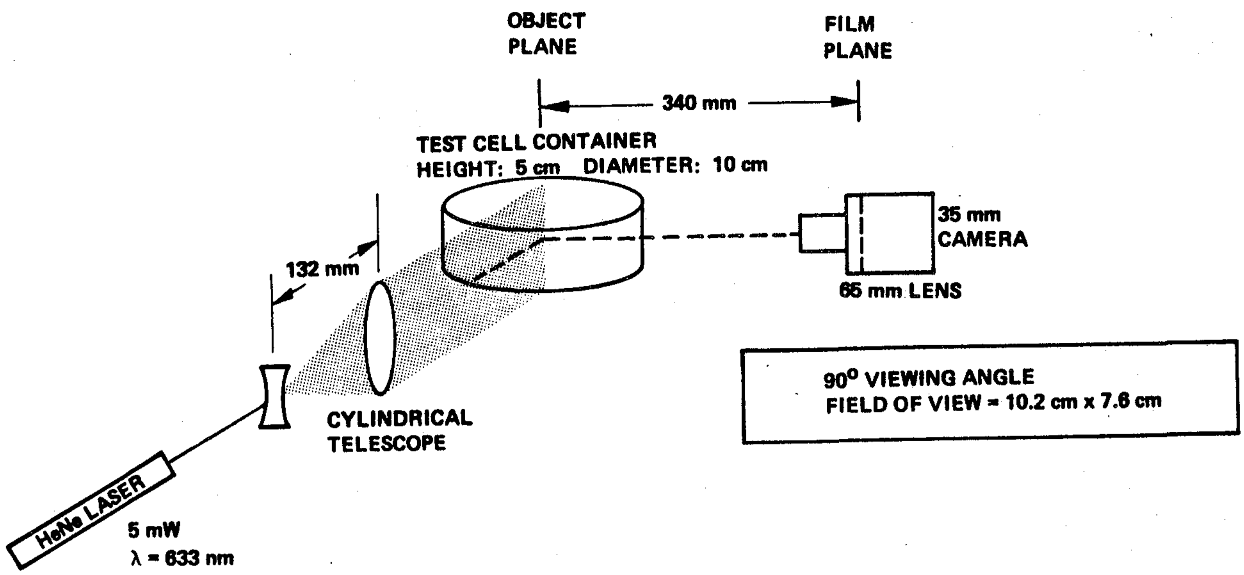


Figure 3.1-13. THE OPTICAL TRAIN FOR SURFACE TENSION INDUCED CONVECTION EXPERIMENT

A cylindrical telescope expands the laser beam in one direction and transforms the laser output into a sheet of light that illuminates a narrow corridor through the center of the experiment container. The beam expanding telescope is shown in Figure 3.1-14. It consists of a cylindrical concave lens (focal length = - 5 mm) and a cylindrical convex lens (focal length = 137 mm) separated by a distance of 132 mm. In the vertical (Y) direction, the 2 mm input HeNe beam diameter is expanded to 55 mm, which fills the test cell height (50mm) and includes a 10% overfill.

In the horizontal (X) direction the beam remains unchanged with an output beam width of 2 mm. The diameter of the concave lens is 10 mm. The diameter of the convex lens is large enough to accommodate the expanded beam of 55 mm and a mechanical lens mount (65 mm). The laser beam is shielded from its emission port through the telescope to eliminate any potential eye damage to the crew.

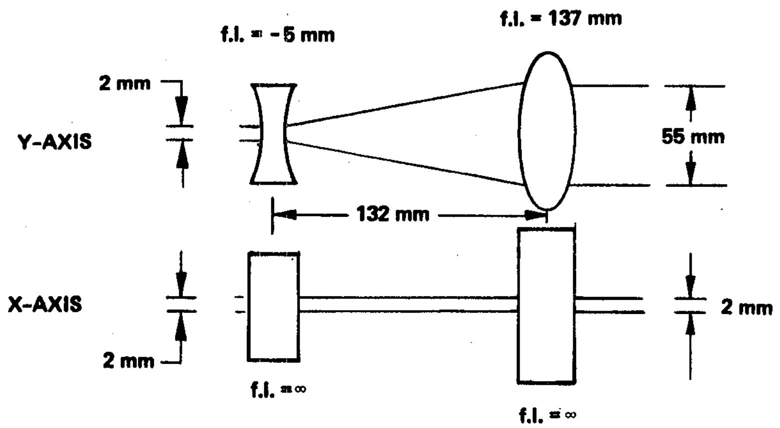


Figure 3.1-14. SKETCH FOR EXPANSION OF HeNe LASER BEAM

The sheet of light passes through the cell and illuminates the entire 10 cm cell diameter with 2 mm thick plane. A 35 mm movie camera with a 65 mm f/3.5 lens views the scattered light at 90 degrees from the plane.

The Camera. The surface tension induced convection experiment requires operation at 10^{-4} g or less for one hour, to maintain this low g level requires that film not be changed. The experiment dynamics require only a framing rate of 1/sec or less. The camera selected is a special modification (4 - S) of the Photo-sonics 35 mm 4ML which has a frame rate of one frame per second (fps) and a maximum allowable exposure time of .4 seconds. The camera must be capable of recording information on ft. cassette if thin-based film is used. The camera also has a built-in data recording system allowing digitized data (temperature and time) to be displayed in a 7 segment format on individual frames. The camera runs on 28 V and requires 56 W to start and 13 W to run. The Photo-sonics 35 mm 4ML camera has been used in space applications previously.

The rate of film exposure will be a critical factor to this experiment. The exposure rate should be such that only one film cassette is used during an entire experiment. Optical alignment simplicity is achieved through a small camera-experiment distance with both hard-mounted and aligned preflight. In this configuration, changing the film in flight will induce significant "g" jitter into the fluid cell and induce extraneous flow. A frame rate of 1 per second is consistent with the analysis of flow rates and will not degrade the experiment data.

<u>Imaging Considerations</u>. The distance between the object plane and the film plane of the camera has been set at 340mm or less by constraints of available space. This distance is the least acceptable that will give a field-of-view of the entire test volume and still minimizes wide angle distortion characteristics of short focal length lenses. The film format for a 35 mm movie camera film is 24 mm x 18 mm and to image an object 340 mm away, a 65 mm focal length lens is required. The angle of view is 20^{o} x 16^{o} and the field of view is 10.2cm x 7.6 cm which covers the test cell. The magnification is 24 mm/102mm = .24.

<u>Film and Exposure Time</u>. Y. Kamotani and T. Kerslake (K&K) (Appendix B) obtained photographs of particle movements induced by surface tension driven convective flows. A comparison of their experimental parameters with the parameters recommended in the proposed design are listed in Table 3.1-10.

Table 3.1-10 COMPARISON OF EXPERIMENTAL PARAMETERS

	ASA Rating	Shutter Speed	Aperture	Laser Power Density
K&K Test	3000	3 sec	f/8	1X
Proposed Design	250	1/2 sec	f/2.8	6X
	500	"	f/4	"
	1000	"	f/5.6	"
	2000	"	f/8	"

Their light source in the laboratory was a diverging 5 mW HeNe laser beam which we estimate used approximately 1/6 of the available wave front. The power density available in an efficiently designed system gives a collimated beam that is at least 6 times the laboratory power density. This is an advantage of 3 camera f-stops. However, their exposure times (3 sec) are longer than the exposure times (1/2 sec) allowed by the Photo-sonics camera, a disadvantage of 2-1/2 f-stops. The design has an overall 1/2 f-stop advantage. Acceptable values of film speed and aperture settings are listed. The ASA-rated film required is commonly available. Note however that there is little intensity margin in the 5mw HeNe laser. The highest power laser that can be accomodated should be used to maximize light intensity.

Background Considerations. The fluid must be free of contaminants, which can serve as unwanted scattering centers that can overwhelm the image and destroy the contrast. Also the particle number density must be kept low enough to prevent multiple scattering.

Film Format Choice. Use of a 35 mm camera has advantages over the use of a 16 mm camera. The 35 mm film format (24 mm x 18 mm) has 4 times the area of the 16 mm format (12 mm x 9 mm) allowing better resolution because the information is not as compressed. The fast films and fast lenses are required for the experiment due to low light levels and a greater variety of high speed film and lenses are available for 35 mm cameras. Likewise, a greater number of black and white film types with extended red sensitivity are on the market for 35 mm and these are more sensitive to the red light specified.

3.1.6.3 Thermal Sensing

Thermistors with a temperature range of 0-100 C are specified. Thermistors are chosen since they simplify the electronics and are conveniently designed into the system. Thermistor insertion is shown in Figure 3.1-2a. The temperature from each thermistor will be sensed a rate of once every four seconds.

3.1.7 Experiment Timeline

The experiment timeline is divided into three steps. The first is a preparation step, during which the experiment is activated and the system placed in a test-ready position. Upon verification of the experimental conditions, the test is initiated in the second step. The sequence of events which takes place during this step is designed to meet the science requirements.

Thus the power to the heater is controlled, at predetermined times relative to the heater. The third step is the termination step in which all systems are secured for stowage and return.

The list of operations in each one of the steps is given in the experiment timeline in Table 3.1-11.

Table 3.1-11. SURFACE TENSION INDUCED CONVECTION EXPERIMENT TIMELINE

Experiment Preparation	Initiate and operate Experiment	Stop Experiment
- Power On	- Start Camera	- Instruments Off
- Instruments On	o Time On	- Lights Off
o Power Meter	- Activated Heater to TBD Watts	- Power off
o Temperatures/ Pressure	- Operate Camera Continuously at 1 FPS for 15 Minutes	- Heater Raised
- Illumination On	- Heater to TBD Watts	- Plug Liquid Container
- Camera Ready	- Camera Operate for 15 Minutes	- Secure Experiment and Container for Landing
- Activate Liquid Solenoid Valves	- Change Heater to TBD Watts	
- Fill Cell to Required Level	- Camera Operate for 15 Minutes	
- Heater Activated	- Heater Off	
- Verify Experiment Conditions	- Stop Camera	
o Fluid Quiescent		
o Illumination Constant		

3.1.8 Thermal Control

For the container no active thermal control is required. Subsystems requiring heat rejection include:

- o Power supplies
- o Camera power
- o Heater casing

Specified method of heat rejection is a muffin fan of the Rotran Spartan Series installed on the structure wall. This fan will circulate cabin air through the experiment volume. The heater air will exit through vents in the structure door, or, if available the backside. Ducting to the component surfaces may be required. Adequacy of the specified unit should be verified by additional development tests.

3.2 SYSTEM ELECTRONICS

The design for system electronics for the Surface Tension Induced Convection Experiment is based upon operating procedures developed in Section 3.1.7.

An electronics block diagram for the experiment is shown in figure 3.2-1. The electronic approach features the following:

- o Manual control of the experiment process.
  - manual on/off
- o Switches wherever feasible.
  - manual operations of valves for fluid flow
- o Temperature sensor readout on film out of scene area and utilizing internal camera functions.
- o Timing control on the camera out of the scene area.
- o DC heater selection of four powers; nominally 2 w, 5 w, 10 w, 15 w.

In operation the master on/off switch activates all units. This switch turns on the fan and laser which operate continuously.

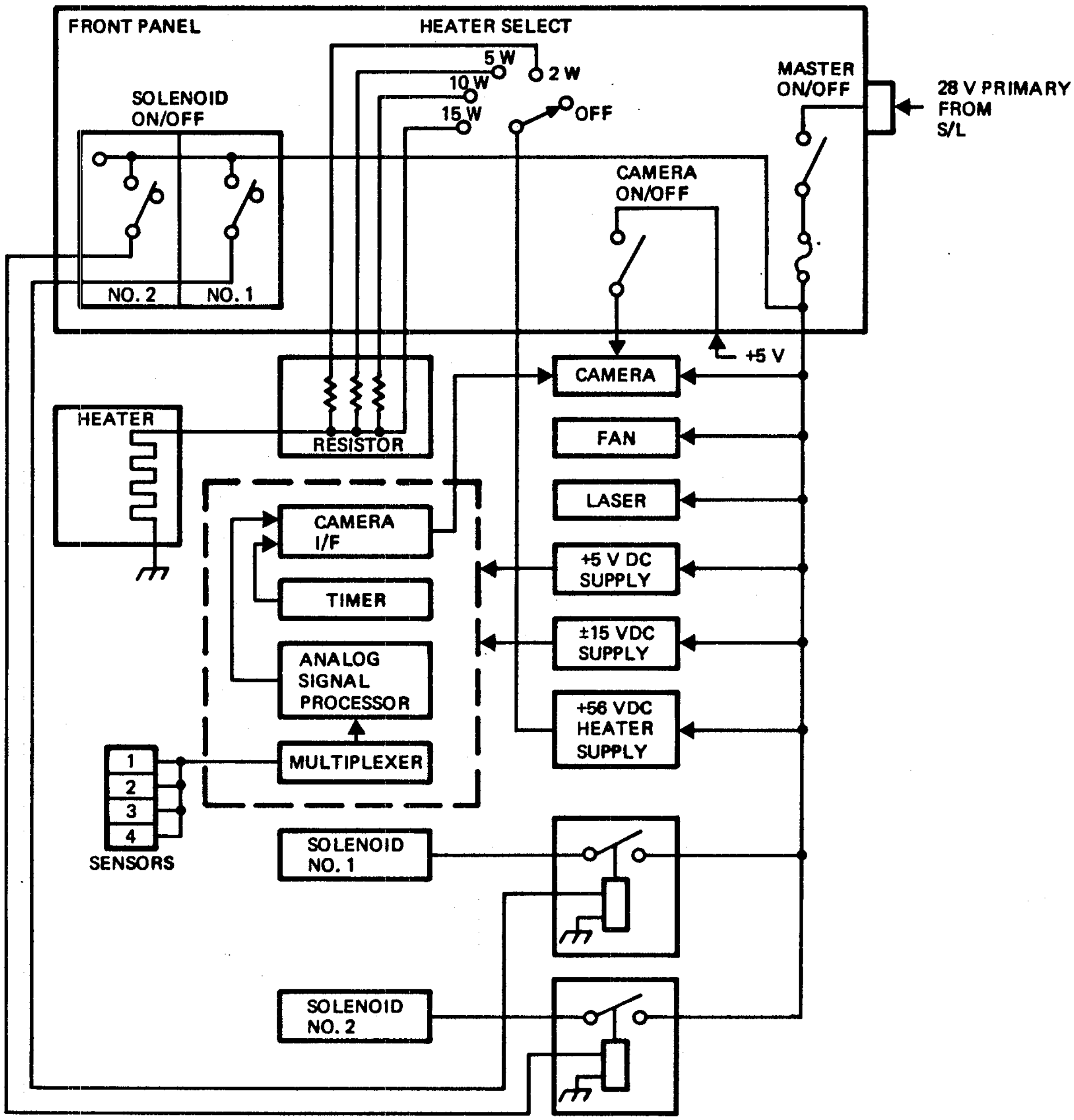


Fig. 3.2-1 SURFACE TENSION INDUCED CONVECTION ELECTRONIC BLOCK DIAGRAM

The particle mixer is activated and mixes continuously for a defined period. Once the master switch is activated the experiment can be sequenced manually through control panel operations.

A typical control panel is shown in Figure 3.2-2. The fluid fill is activated by two solenoid valves. It is planned that the pressure will be preadjusted and no inflight change will be necessary. However, If the fill rate is inappropriate the drive pressure can be adjusted at the panel.
When the cell is filled with fluid the solenoids are shut off. The heater power is set to position 1, and the camera and heater are activated manually. After the appropriate heating time the heater and camera are turned off. Then a second heater power is selected, and the experiment operated. This cycle occurs until all heater powers required are activated. During camera operation it receives one thermistor datum or a time marker per frame. This results in each sensor being recorded every five seconds during the heating process. The temperature sensors produce analog data. This data is multiplexed and is then channeled through the camera interface unit. From there it is sent to the camera where it is recorded as part of the film record. The use of the camera for data recording eliminates the need for a data recorder.

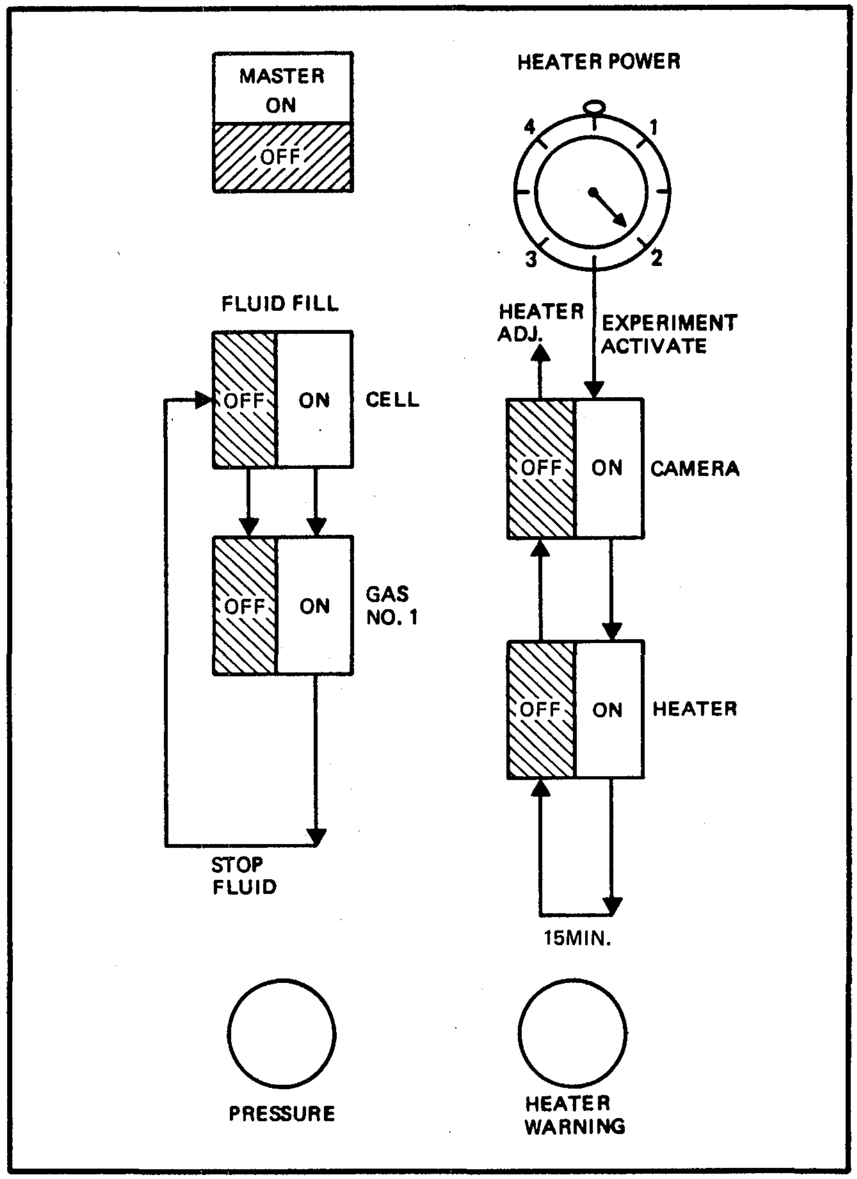


Figure 3.2-2. TYPICAL CONTROL PANEL

The estimated power consumption has been estimated based upon the above design. The power for two cell fill and experiment are:

I. Cell Fill Operation

Fan	34 watts
Motor (Stirrer)	15 watts
Valve Operation	5 watts

–54 watts

II. Experiment Operation

Camera	56 watts
Heater	20 watts
Motor	15 watts
Fan	34 watts
Electronics	20 watts

–145 watts

Mid-deck power available to the experiment will range from 165 watts to 224 watts dependent upon the bus used. A secondary consideration is that the current to all sources be less than 5 amps if possible. The current design of the Surface Tension Induced Convection Experiment is within these constraints.

3.3 EXPERIMENT LAYOUT

A layout of the experiment is shown in Figure 3.3-1. A corresponding isometric view of the experiment including major components is shown in Figure 3.3-2. The experiment is packaged into the volume of two adjacent lockers which contain both the experiment hardware as well as the control electronics and the data acquisition system. The specific layout provides:

- A full field of view of the cell plane at the camera.
- Access to the cell through the window (or door in the front panel).
- A window to view the cell.
- Shielding of laser light from the crew.
- Mechanism to fill the gas pressure bottle and the accumulator after assembly with the front panel off.
- Pressure control at the front panel.
- A fully enclosed system under operating conditions.

The window will be removable so that the crew can gain entrance to the experiment interior. This will accommodate any in-flight adjustments that may be required. A door can be provided if desired to have greater access. Under manual operating minimal access is antipicated. Should multiple cells be indicated in the future cell units can be interchanged using a quick disconnect. Additional storage must be provided.

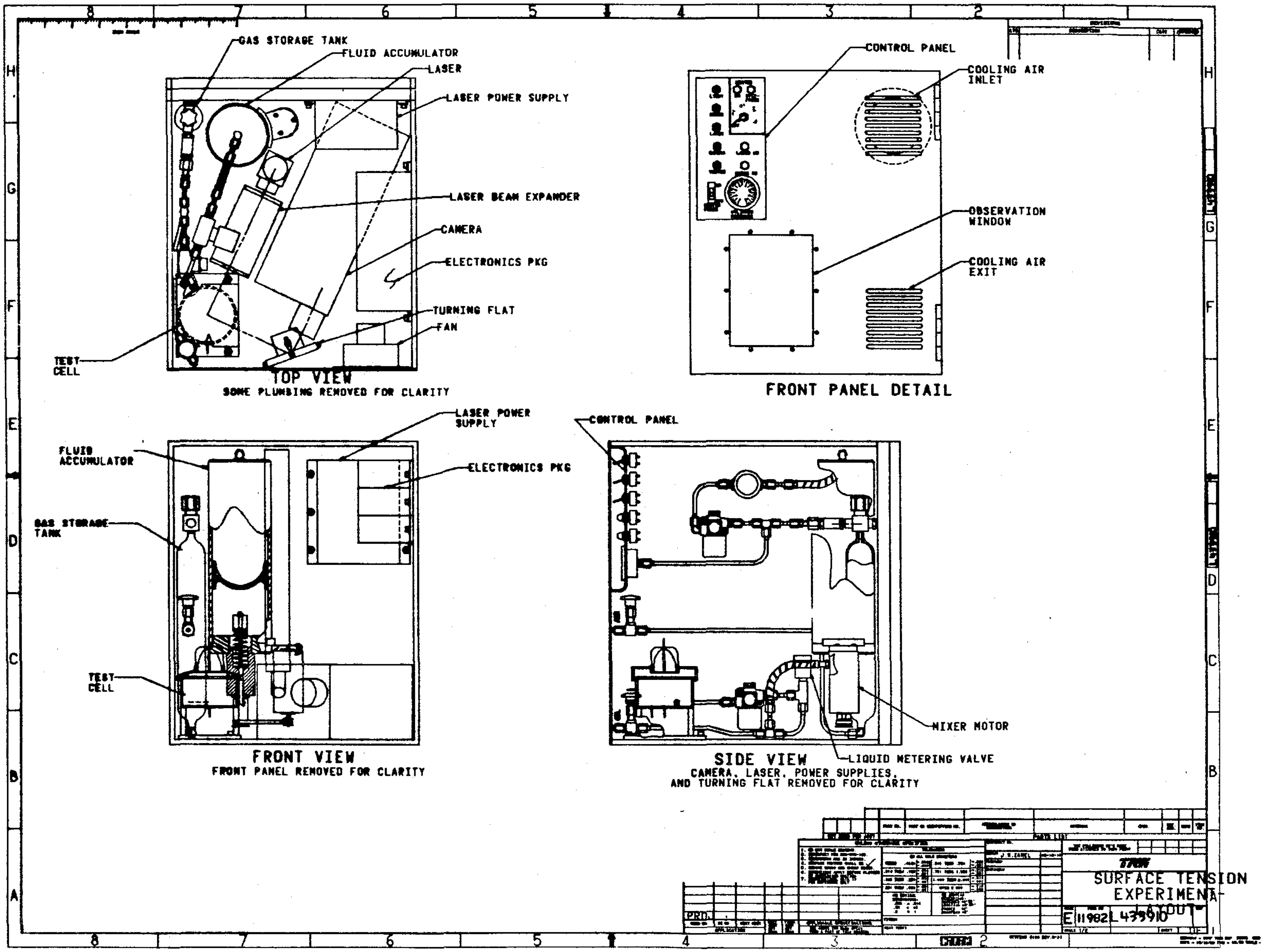


Fig. 3.3-1 SURFACE TENSION INDUCED CONVECTION EXPERIMENT LAYOUT

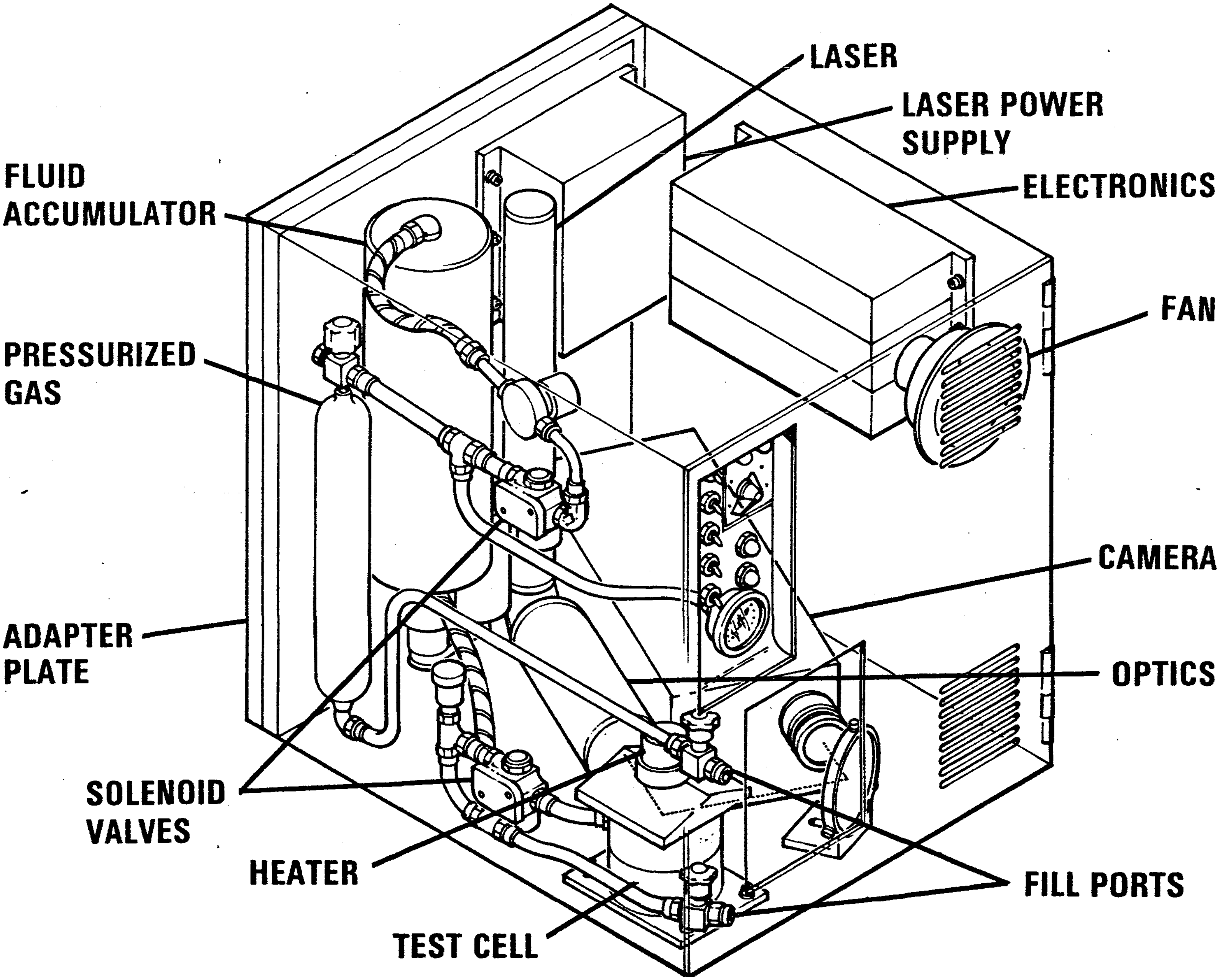


Figure 3.3-2 Surface Tension Induced Convection Experiment Isometric Drawing

The current design uses a 35mm camera. The reasons for this are detailed in 3.1.6. The camera is a design driver in both dimension, volume and mass. The camera is accommodated in this design only by fitting it diagonally in the two locker volume. Due to the predicted exposures of up to seconds the camera must be stabilized and vibrations of the test container relative to the camera must be eliminated in the design.

A list of major subsystem and parts are given in Table 3.3-1.

3.4 WEIGHT ESTIMATE

The weight is estimated based upon the experiment design. The weight of identified components are given in Table 3.3-1. Weights for items reqiring detailed design such as

- o optical assembly including the laser
- o fluid storage
- o cell
- o fluid drive assembly
- o power supplies
- o optics
- o enclosure and door

are estimates based upon current design philosophy. Therefore the total weight given below is only a preliminary estimate.

Table 3.3-1 Surface Tension Driven Convection Experiment Major Equipment List

COMPONENT	DIMENSION	VOLUME	TYPICAL SUPPLIER
Experiment Container	12cm x 12cm x 8cm	$1. \times 10^{-3} M^3$	Fabricated
Fluid Accumulator (Fluid Storage)	6.78(d) x 39cm	$0.019 M^3$	Parker Hannifin A4A0116B
Gas Storage	35.6 x 5.08(d)cm	$7 \times 10^{-3} M^3$	Whitey 304-HDF4-500
Camera (35mm)	13.7 x 31.1 x 14.9cm	$.6 \times 10^{-3} M^3$	Photo-Sonies
Illumination Laser 5 mw	4cm x 4.42cm dia.	$.6 \times 10^{-3} M^3$	Spectra Physics TBD
Optics	73.2 x 7(dia)cm	$0.3 \times 10^{-3} M^3$	Fabricate
Heater	1.0(d) x 4.50	Small	Watco Special design
Power Supplies	15cm x 26cm x12cm	4.7×10^{-3}	Fabrication
Fan	7.6cm(dia) x 3.8	$2 \times 10^{-3} M^3$	Roton
Mixer Motor	Small		Pittman Corp.
Cylinder Valve	Small		Whitey SS-16DKM4-F4-A-RD
Solendoid Valve	Small		Marotta Sc. MV100-206003
Regulator	Small		TBD
Fill Valves	Small		Whitey SS-1 K54
Air Filter	Small		Nupro SS-41F2-15
Metering Valve	Small		Nupro SS-4LA
Flex Hose	Small		Crawford Upper SS-4H0-6-5 4 Lower SS-4H0-1-54

The adaptor plate weights used are those currently given in Reference 2.2. It is our understanding that two lightweight single adaptor plates weighing 3.5 lbs. each can be used instead of those specified. The double adaptor plate is not required if the appropriate structure is used. We estimate a saving up to 15 lbs. using the lightweight adaptor plates and atachments to them.

The weight as currently derived is about 105 lbs. The weight is within the 120 limit even using the heavier adaptor plates. In this design, the c.g. is within 10" of the attachment points as required.

3.5 EXPERIMENT STATUS AND RECOMMENDATIONS

The design of the Surface Tension Induced Convection Experiment reported here reflects the requirements as given in Reference 1.1 and Table 1.2 as modified at the Conceptual Design Review and incorporating later requirements changes. The experiment volume and weight are compatible with incorporation into a double locker in the STS mid-deck. Critical design drivers in the volume are:

- Field-of-view (FOV) at the observation plane. Currently the whole cell diameter and the cell height are in the FOV. This is accomplished using a 35 mm camera. Maintainence of a 10^{-4} "g" level requires that the film not be changed during an experiment. This mandates a 1fps rate for continuous experiment coverage.

- Maximize the laser power. The required exposure time will be dependent upon the light scattered by the suspended particles. This increases with the intensity of the laser. Thus the higher power the laser the more favorable the observation a five milliwatt HeNe laser is the largest unit that can be contained in two vertical lockers in any dimension. Results of the analysis and tests at CWRU indicate that 5 mw of laser power scatters sufficient light from a 3μm particle to sensitize the film.

- Containment of all fluid within the experiment container. This is achieved by the close coupling of the heater housing to the container and plugging the container at the experiment conclusion if required.

- Environmental Control. This is achieved through the use of a fan placed in the experiment structure. The fan may require ducting to heat sources such as the camera; the power supplies and the heater. Further analysis is required to determine the exact size and the weight of the fan.

- Optical Alignment. Structural integrity must be provided between the film plane and cell to accommodate the anticipated exposure times. The detailed design must provide further vibrational analysis.

The power constraints for the mid-deck are met by this experiment.

The areas of design that require further definition of requirements follow.

Temperature Measurement. Four temperature sensors can be accommodated by the camera. The position of these sensor must be specified to maximize experiment data.

3.6 SAFETY

The Hazard Reports and the Safety Matrix are included as Appendix E. The major safety features that must be designed into the experiment are:

- Protection from heater runaway
- Direction of laser beam
- Fluid containment and use of non-flammable fluid.

None of these is considered a major design driver. This is especially true at the reduced heater power. The heater will be protected against runaway by an automatic turn-off activated when a maximum power level is reached.

The fluid selected must be compatible with STS operation. In particular, tests of fluorocarbon by-products must be made if this fluid is used.

The laser beam is totally shielded from the crew through its expansion into a plane sheath. The laser light viewed at the container is below the threshold for eye damage. Further analyses must be made using final design parameters to verify this.

4. FREE SURFACE PHENOMENA UNDER REDUCED GRAVITY

The concept and preliminary design of this experiment meets the science requirements as given in Reference 1.3 in so far as possible in the mid-deck arrangement. The arrangement of material in this report is the same as that in the sections concerning the Surface Tension Induced Convection Experiment (Section 3).

The equipment functions are laid out in Figure 4-1. We follow the subsystem development as given in this figure.

4.1 EXPERIMENT REQUIREMENTS, CONCEPTS AND PRELIMINARY DESIGN

This section discusses the experiment requirements, describes the conceptual development and gives preliminary drawings of the subsystems and components. The experiment is divided up into the following subsystems.

a) Experiment container

b) Fluid

c) Fluid Delivery

d) Experiment operation

e) Diagnostics

f) Thermal control

g) Storage

4.1.1 Experiment Container

Table 4.1-1 gives the requirements and their implementation. A conceptual design and assembly technique for a container which meets the experiment requirements is shown in Figure 4.1-1. The container body (3) is made of a clear polymer material such as

FUNCTION FLOW

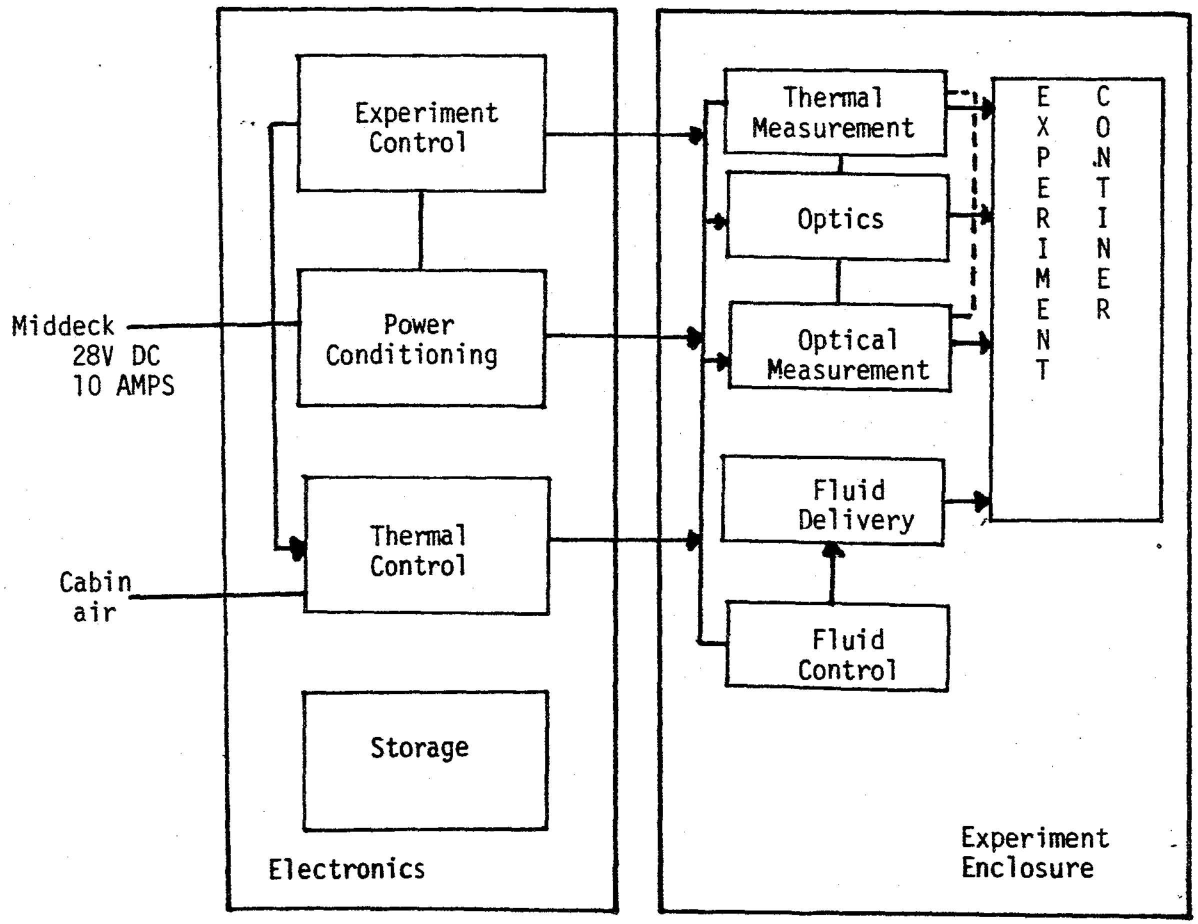


Figure 4-1 FREE SURFACE PHENOMENA EXPERIMENT FUNCTION FLOW

TABLE 4.1-1 EXPERIMENT CONTAINER (CONT.)

REQUIREMENT	SOURCE/COMMENTS	IMPLEMENTATION
I-6 SURFACE MATERIAL COMPATIBLE WITH CONTACT ANGLE	• MATERIAL MUST BE APPROPRIATE FOR CONTACT ANGLE • SHUTTLE CONSTRAINTS WILL LIMIT AVAILABLE MATERIALS • DEVELOPMENT TESTS INDICATED	• MATERIAL - TBD • PLEXIGLASS IS TO BE CONSIDERED
I-7 FLUID HEIGHT RESOLUTION ± TBD CM.	• MEASUREMENT OF FLUID DISTRIBUTION AS A FUNCTION OF TIME	• INSCRIBE MESH PATTERN ON THE OUTER SURFACE
I-8 EVEN FLUID OVER ENTIRE BOTTOM SURFACE	• FLUID MUST ENTER ENTIRE FILL AREA UNDER LOW GRAVITY	• USE A POROUS FLOW PLUG, e.g., DYNALLOY FILTER MEDIA
I-9 MEASUREMENTS OF FLUID TEMPERATURE	• FLUID SHOULD BE AT AMBIENT AND TEMPERATURE CHANGES ARE NOT EXPECTED	• EXPERIMENT BEGINNING - END ONLY • OUT OF LIMIT TEMPERATURE ALERT
I-10 FLUID CONTAINMENT	• SHUTTLE IMPOSED CONTAINMENT OF ACCIDENTAL SPILL	• USE OF DOUBLE WALL VESSEL TO CONTAIN FLUID

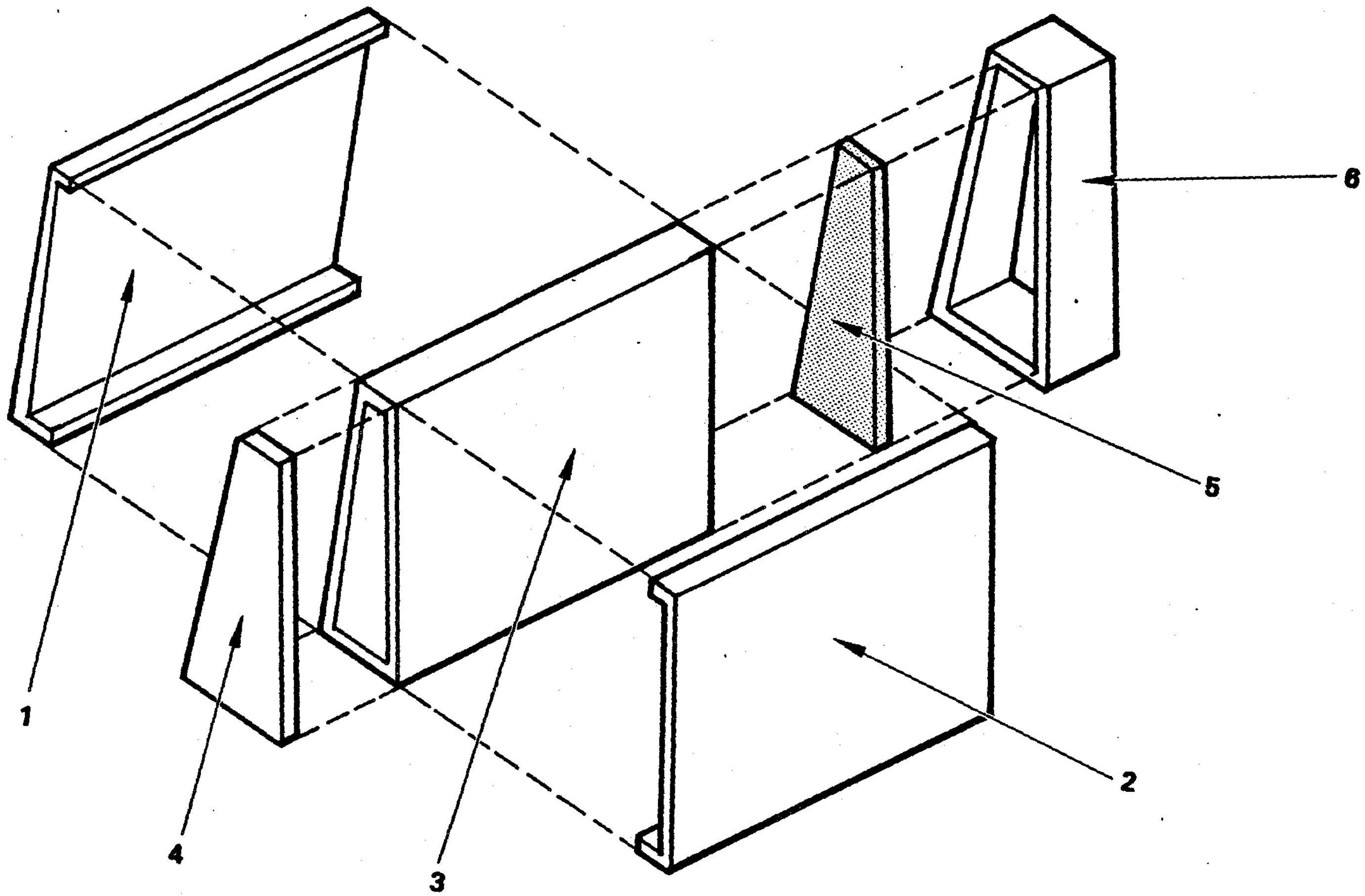


Figure 4.1-1 EXPERIMENT CONTAINER ASSEMBLY

polycarbonate or acrylic. The material must be transparent to the illumination and transmit the fluid image to the camera. The cell length is determined by the maximum dimension that is accommodated by the experiment volume. This determined the 45 cm length. The container body (3) is fabricated is made by injection molding or by cementing the two halves (1) and (2) to form the body (3). The accuracy and sharpness of the interior angles of the container and the interior smoothness of the container walls are critical to the experiment operation. The accuracy and the smoothness criteria have not been defined. The top cover (4) is used to contain the fluid with the cell but includes a 1mm breathing part to allow for the displacement of air as fluid flows into the test cell. The bottom (5) consists of a porous metal frit which will allow even flow of liquid over the bottom. A container base (6) contains the interface between the vessel and the feed system to be shown later and space below the frit.

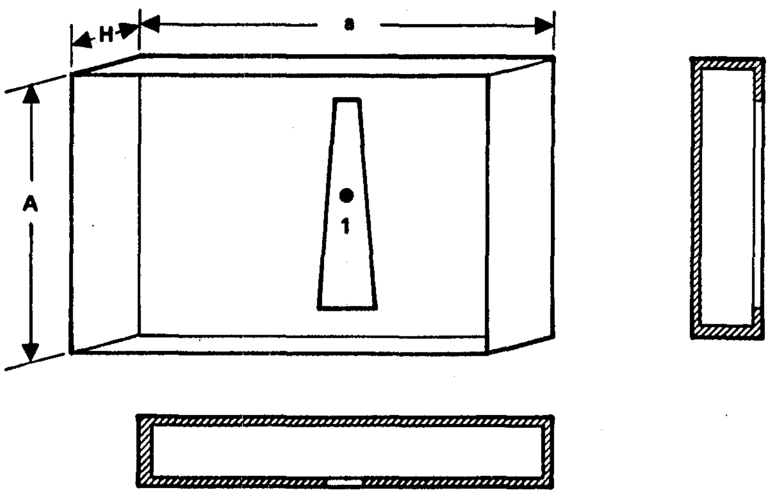


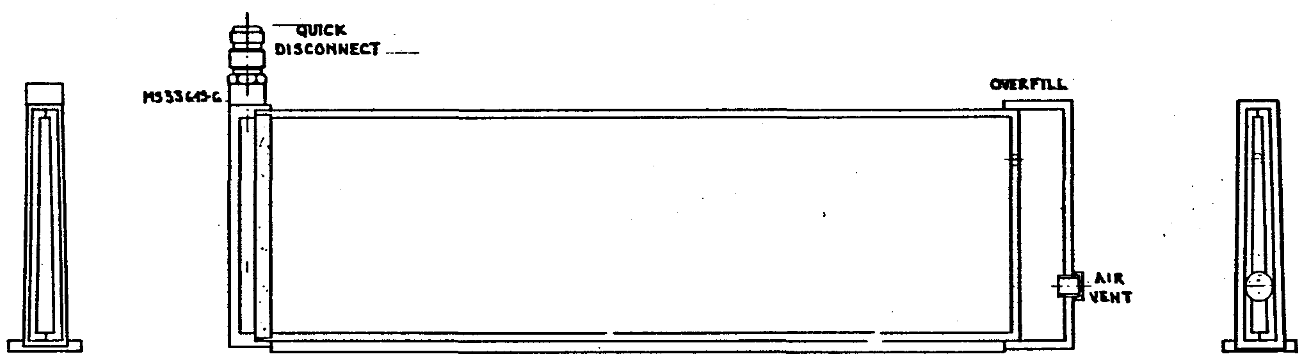
Figure 4.1-2 OVERFILL CONTAINMENT VESSEL

An overfill volume for the experiment container is schematically shown in figure 4.1-2. This is placed over the test cell so that liquid that does penetrate through the breathing part is contained. This volume does not accommodate the total cell volume since there should be minimal overflow through the 1 mm hole.

The container design is shown in Figure 4.1-3. The features on the cell not previously discussed include 1) a 1 mm breathing port to the STS environment that will be plugged with glass wool and 2) the quick disconnect to the fluid feed.

4.1.2 Fluid

Table 4.1-2 summarizes the test liquid requirements and implementation. The contact angle between the liquid and the container is a key parameter in the experiment, and the selection of the fluid is dependent upon the test cell material. In addition, the liquid has to satisfy all the safety requirements imposed by the shuttle environment. The most promising candidate liquids are, Fluorocarbons or sicicon oils. A partial list of fluorinert (TM) and silicon oil fluids is given in Table 3.1-4. The fluids in that table were selected for their high boiling temperature. Liquids in this experiment see only ambient temperatures. However, a low vapor pressure is a requirement and these fluids satisfy that requirement. The fluid selection must be made in combination with the selection of the experiment container material.



SIZE C	FSCM NO. 11982	FREE SURFACE PHENOMENA CELL
SCALE HALF		SHEET

L 702496

Fig. 4.1-3 CONTAINER DESIGN

Table 4.1-2 FLUIDS

REQUIREMENT	SOURCE/COMMENTS	IMPLEMENTATION
II-1 CONTACT ANGLE 58° ± 3°	• RFP AND PREVIOUS PI ANALYSIS • CONTACT ANGLE IS FLUID - MATERIAL DETERMINED • ANY ADDITIVES MUST BE INCORPORATED INTO CONTACT ANGLE EVALUATION • WATER - ETHANOL USED PREVIOUSLY	• STUDY USE OF FLUOROCARBONS AND/OR SILICON OILS
II-2 4 EXP - VOLUME - 562 CM^3 (1/4 TUBE VOLUME PER EXPERIMENT)	• 4 X CYLINDER VOLUME • NO FEED LINES INCLUDED	• DESIGN 700-750 CM^3 VOLUME
II-3 LIQUID LEVELS MUST BE RECORDED DURING EXPERIMENT	• LIQUID SHOULD HAVE COLOR OR SIGNIFICANTLY DIFFERENT INDEX OF REFRACTION	• DISSOLVE SMALL AMOUNT OF DYE IN THE FLUID TO GIVE DARK COLOR
II-4 SHUTTLE COMPATIBLE FLUID	• FLUID MUST NOT BE ADMITTED AT HIGH CONCENTRATIONS OR AT TOXIC LEVELS IN MID-DECK	• USE INERT - NON-TOXIC FLUID WITH A LOW VAPOR PRESSURE

TABLE 4.1-3 FLUID DELIVERY SYSTEM

<table>
<tr><th>REQUIREMENT</th><th>SOURCE/COMMENTS</th><th>IMPLEMENTATION</th></tr>
<tr><td>III-1 DELIVERY RATE RANGE -
TBD CC/MM - TBD CC/MIN</td><td>• CONSTRAINED BY TWO FACTORS
- INSURING THAT FLUID COVERS TOTAL PLATE
- FLUID SHOULD NOT LAG SURFACE CLIMB RATE AND BREAK THE SINGLE LIQUID VOLUME</td><td rowspan="2">• PISTON AND CYLINDER FORCED FEED SYSTEM
• MOTORIZED DRIVE WITH ON/OFF SWITCH
• PRE-DETERMINED TIMING
• BASELINE SINGLE FEED RATE FOR ALL EXPERIMENTS</td></tr>
<tr><td>III-2 FLUID DELIVERY ACCURACY
± TBD CC/MIN</td><td>• NOT REGARDED AS CRITICAL ISSUE</td></tr>
<tr><td>III-3 FLUID VOLUME 750 CM^3</td><td>• SEE II-2
• TRADE PACKAGING SHAPE AND STROKE VS ACCURACY IN FLUID DELIVERY RATE</td><td>FEED CYLINDER DIMENSIONS IN CENTIMETER
<table><tr><th>Option</th><th>Diameter</th><th>Length</th></tr><tr><td>1</td><td>5</td><td>29.0</td></tr><tr><td>2</td><td>10</td><td>7.2</td></tr><tr><td>3</td><td>15</td><td>3.2</td></tr></table></td></tr>
</table>

The fluid for the experiment can have a small amount of a dye dissolved to enhance contrast between the fluid and the container walls.

4.1.3 Fluid Delivery System

Table 4.1-3 gives the fluid delivery system requirements and implementation. The delivery system design for this experiment is the same system described in the surface tension driven convection experiment. An alternate system is the use of a stepper motor drive. A conceptual delivery system as applied to the Free Surface Experiment is shown in Figure 4.1-4.

The fluid drive mechanism is connected to the experiment container via a quick disconnect. The Free Surface Experiment has a porous plate to given even flow over the entire experiment bottom. The analyses in Appendix A applies and the Weber Number must be less than four. The pore size also determines the pressure required to drive the liquid. The smallest pore size conistent with the pressure that can be applied will result in the highest velocity. Typical pore sizes of 20 μm will result in a velocity of 35 cm^3/sec. The limiting flow rate will be of this order of magnitude.

The flow rate required to perform this experiment has not been determined. If the fluid climbs the walls there must be a kinetic rate asociated with this phenomena. A very fast fluid rise time is indicated in drop tower tests which may not be consistent with the limited flow rate.

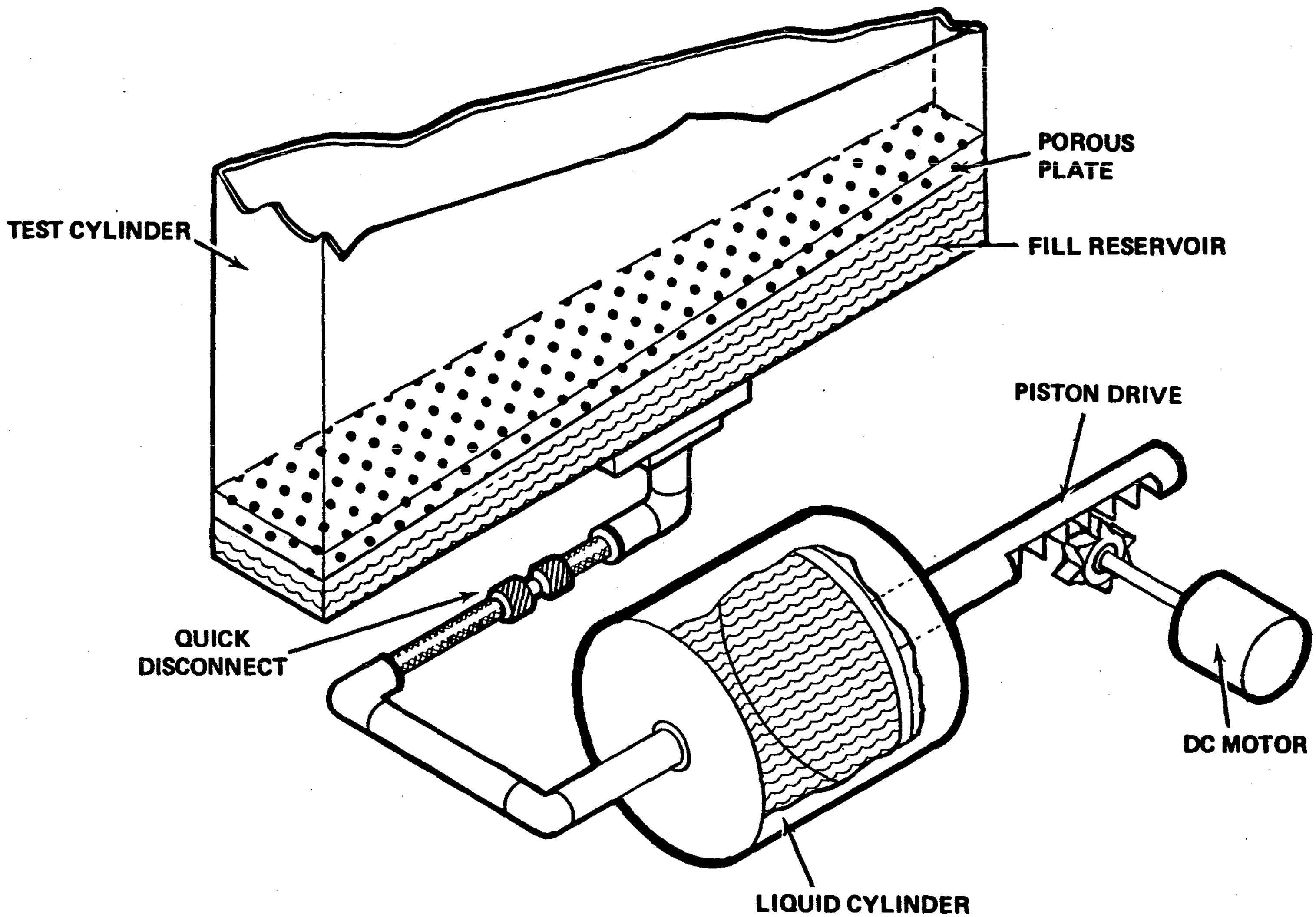


Figure 4.1-4 FLUID DELIVERY SYSTEM CONCEPT

Further analysis and tests must be performed to determine the appropriate velocity and its method for achievement.

A further parameter requiring determination is the minimum depth between the porous plate and the bottom. (Fill resorvior Figure 4.1-4). This distance should be such that it minimizes bubble formation and maintains flow conditions. Bubbles are undersireable but need not be rigidly excluded. The fluid drive system specified is the same as for the Surface Tension Induced Convection Experiment.

4.1.4 Experiment Operation

The experiment operation requirements and implementation are summarized in Table 4.1-4. The orientation of the test cell within the experiment structure, affects the g levels that seen by the fluid. The acceleration forces acting on the Shuttle during orbit can be broken down into forces due to drag (parallel to the direction of motion), earth gravity and vibrations. The magnitude of all of these forces depends on the specific activity and the orientation and flight maneuver of the Shuttle. The test cell should be oriented such that the highest g-level will be aligned parallel with the long axis of the cell during the test. It is also required that the g level be 10^{-5} during the experiment. This may not be achieved in mid-deck on all flights.

TABLE 4.1-4 EXPERIMENT OPERATING CONDITIONING

REQUIREMENT	SOURCE/COMMENTS	IMPLEMENTATION
IV-1 a) TEMPERATURE, AMBIENT b) PRESSURE, AMBIENT	• PI ANALYSIS • PI ANALYSIS	• NO THERMAL CONTROL OR CHAMBER SENSOR • NO PRESSURE SENSOR
IV-2 G, LEVEL < 10^{-5}	• PI REQUIREMENT $B_o = \frac{\rho g L^2}{\sigma} = 10^{-3}$ (ρ = DENSITY; g = GRAVITY LEVEL; L = CHARACTERISTIC LENGTH; σ = SURFACE TENSION)	• ESTABLISH BY STS STABILITY • ACCELERATOR REQUIREMENT TBD
IV-3 USE NO MORE THAN TWO MID-DECK LOCKERS	• RFP • MAINTAIN SIMPLICITY • OVERALL VOLUME H X L X D = 27.3 X 43.5 X 51.6	• USE ONE LOCKER FOR EXPERIMENT EQUIPMENT • USE SECOND LOCKER FOR ELECTRONICS AND CONTAINER STORAGE
IV-4 VIEW EXPERIMENT CONTAINER WITH FLUID FROM TWO DIRECTIONS DURING FLUID FILL	• PI ANALYSIS	• FOV TO BE WIDE AS POSSIBLE BUT LIMITED BY OVERALL PACKAGE DIMENSIONS • USE MIRRORS TO VIEW 2 ANGLE • BACKLIGHT CONTAINER USING TBD LIGHT SOURCE

TABLE 4.1-5 DIAGNOSTICS

REQUIREMENT	SOURCE/COMMENTS	IMPLEMENTATION
TEMPERATURE MEASUREMENT AT START OF TEST	• PI REQUIREMENT • MAKE SURE THAT NO THERMAL GRADIENTS EXIST WITHIN THE TEST CELL (USE "COLD" BADKCGOUND ILLUMINATION)	• SINGLE THERMOCOUPLE RANGE 10-50^{o}C • USE FLUORESCENT LAMP SOURCE
VIEW EXPERIMENT FROM TWO ANGLES DURING	• LIQUID CLIMB REQUIRES .1 SEC ACCURACY • AFTER COVERING BOTTOM HOLD ONE MINUTES • FILM THE EVENT AT MAXIMUM POSSIBLE FRAME RATE FOR A SHORT PERIOD OF TIME	• PHOTOGRAPHY METHOD OF CHOICE • TRADE 16 MM VS 35 MM CAMERA • CAMERA FIXED POSITION • FILM FOR FOUR EXPS PREFERABLY CONTAINED IN SINGLE MAGAZINE/ CASSETTE • ALWAYS RECORDS TWO VIEW SPLIT FIELD OF VIEW
EXPERIMENT TIME	• TBD	• CAMERA SYNC TIME
ACCELERATION	• MEASURE ACCELERATION IN 3 AXIS	• PROVIDE A 3-AXIS ACCELERATION DATA TO BE RECORDED DURING TEST RUN

4.1.5 Diagnostics

The summary of the diagnostics requirements and implementation is given in Table 4.1-5

4.1.5.1 Temperature

No thermal gradients can be induced along the long axis of the test cell. Only one temperature reading is required that of the ambient air. A "cool" light source can be used. Appendix D describes qualified florescent lamp system which meets the requirements. The ILC lamp is space-qualified and has a touch temperature of 45 C or less. This lamp can be built to meet the experiment requirements.

4.1.5.2 Photgraphy

The entire length of the test cell must be viewed during the experiment. This means that the cell length may be contained by the field -of-view. In the two lockers arrangement the camera-to-cell distance is optimized at about 18" (45.7 cm) and analyze the field-of-view (FOV). FOV and the depth-of-field (DOF) are calculated for two formats, using 16mm or a 35mm camera. The film area is 1.02 cm x 0.742 cm for a 16 mm camera and 2.4 cm x 3.6 cm for a 35 mm camera. Since the experiment does not require special close-up capabilities, the standard circle of confusion of c=0.001" is assumed. Comparison between the two formats is given in Table 4.1-6.

The results indicate that the 35 mm camera is preferred since it has larger FOV (due to larger format). A 16 mm camera

Table 4.1-6

COMPARISON BETWEEN FIELD-OF-VIEW AND DEPTH-OF-FIELD WITH TWO DIFFERENT FORMATS*

16 mm camera

lens focal length (mm) (magnification)	FOV in cm Depth-of-Field in cm
10 (0.0224)	30 x 40.6 22.8 to inf. (f/22) 41.8 to 50 (f/2)
12.5 (0.0281)	25.4 x 38.1 25 to inf. (f/22) 42.6 to 49.3 (f/2)
16 (0.0363)	11.1 x 8.0 28.1 to 123. (f/22) 43.2 to 48.5 (f/2)

35 mm camera

lens focal length (mm) (magnification)	FOV in cm Depth-of-Field in cm
18.5 (0.042)	85.7 x 57.1 29.6 to 100 (f/22) 43.5 to 48.1 (f/2)
25 (0.0579)	62.2 x 41.4 32.6 to 76.4 (f/22) 44.1 to 47.4 (f/2)
28 (0.0653)	55.1 x 36.8 33.6 to 71.3 (f/22) 44.2 to 47.2 (f/2)
35 (0.0829)	43.4 x 28.9 35.5 to 64.1 (f/22) 44.5 to 46.9 (f/2)

* All cases lens focused to 18" (45.7 cm) and circle of confusion on film is 1/1000".

with a wide angle (10 mm) lens has as wide a FOV, but the demagnification is worse. The DOF is usually better for a 16 mm camera because of the smaller format. When a print is magified, the 35 mm format gives a sharper image.

The conclusion is that a 35 mm format should be used provided the physical size can be accomodated and the frame rate is sufficient. The Photo-Sonics 4 ML high speed camera is a potential unit. It has frame rate from 10 to 200 fps,; film capacity of 200 ft., 400 ft. or 1000 ft. using magazines, dimensions are 12.3" x 5.4" x 6" with 200' magazine, and 15.4" x 7.6" x 6" with a 400' magazine). A 90 lens adapter is available. This camera is accommodated in our design.

The optical arrangement utilizes a mirror to allow simultaneous observation of the test cell for two directions. It also leaves enough space to place four digital readouts within the FOV. These are the 3 axis accelerometer and the temperature sensor. The fluid behavior as well as the supporting data are recorded on film.

The film rate and total footage available limit the viewing time. The viewing time is divided into four for the four experiments. To best utilize the available footage, the test should be filmed during the liquid fill at a high frame rate. The strategy will allow observation of liquid climbing the wall or free surface phenomena, but will not leave much film to photograph the final steady state.

TABLE 4.1-7

EXPERIMENT TIME LINE

EXPERIMENT PREPARATION →	EXPERIMENT RUN →	EXPERIMENT TERMINATION →	EXPERIMENT COMPLETED
- INSTALL CYLINDER #1, CONNECT QUICK - DISCONNECT LINE, CONNECT T/C WIRE	- START CAMERA AND LIQUID FEED	- CLOSE FEED VALVES	- STORE ALL FOUR TEST CELLS INSIDE EXPERIMENT STRUCTURE
- POWER ON	- AUTOMATIC SHUT-OFF	- DISCONNECT TEST CELL AND REMOVE	- SECURE
- VERIFY TEST CONDITIONS g LEVEL, TEMPERATURE		- INSTALL NEXT TEST CELL	- POWER OFF
- CHECK CAMERA READY SPEED SET, LIGHTS ON		- REPEAT AS BEFORE	
- OPEN FEED VALVES, FILL FEED LINES WITH LIQUID			
- VERIFY TEMPERATURE AND g DISPLAY-ON			

4.1.6 Experiment Operation

The experiment time-line is shown in Table 4.1-7. The experiment consists of four steps. The first is a preparation step in which the equipment is prepared for a test, the second is the actual test run which is initiated and carried out automatically.

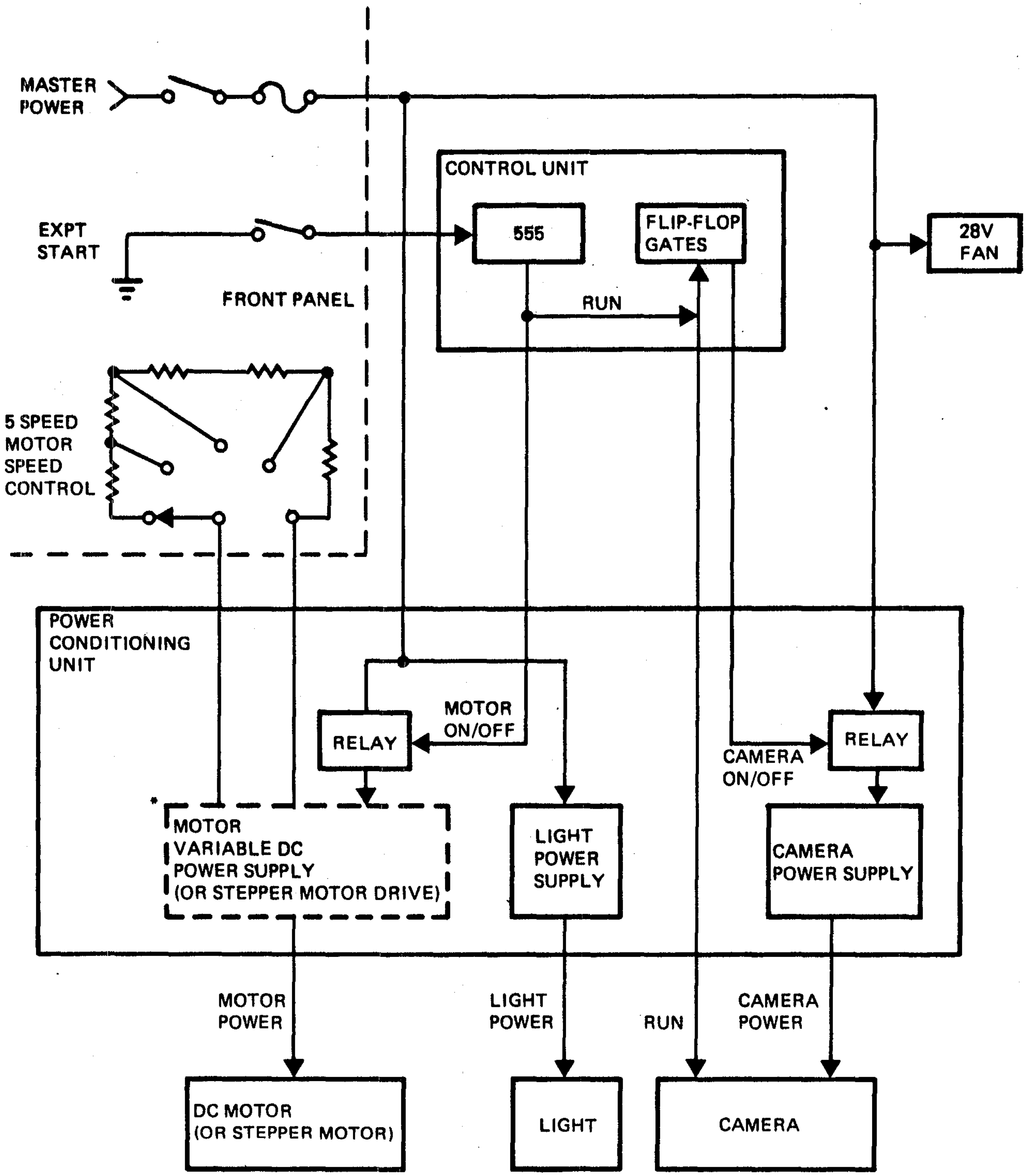


Figure 4.2-1 FREE SURFACE PHENOMENA EXPERIMENT ELECTRONIC LAYOUT

The following step involves the removal of the filled test cell and preparation for the next test. During each test run, the extra three test cells can be kept outside the experiment enclosure to allow vusual inspection, and working access.

4.1.7 Thermal Control

The Free Surface Phenomena Experiment requires no thermal control of the fluid in storage or during the experiment. Heat rejection from the camera power supply will be required. The specified unit is a muffin fan as listed in Table 3.3-1.

4.2 SYSTEM ELECTRONICS

The system electronics for the Free Surface Phenomena Experiment are developed from the operating parameters above. The experiment operation requires short time intervals during operation and therefore is automated. The electronic block diagram for the experiment is given in Figure 4.2-1. The experiment design has three functions that require the control panel operation:

- a power on - power off switch
- an experiment start switch
- an experiment select switch

The power on/off switch activates the power supplies; the fan; and the light source. The experiment selector switch identifies the cell and determines the motor speed to the fluid drive - if this varies between experiments or if a different speed is indicated.

The experiment start switch activates the experiment control which at pre-determined times activates the camera then the motor to flow fluid into the cell. If an accelerometer is included in the experiment design the accelerometer outputs are displayed at LED's in the camera FOV. The circuit operation is shown in Figure 4.2-2. There is provision for four displays and time or experiment temperature can be included.

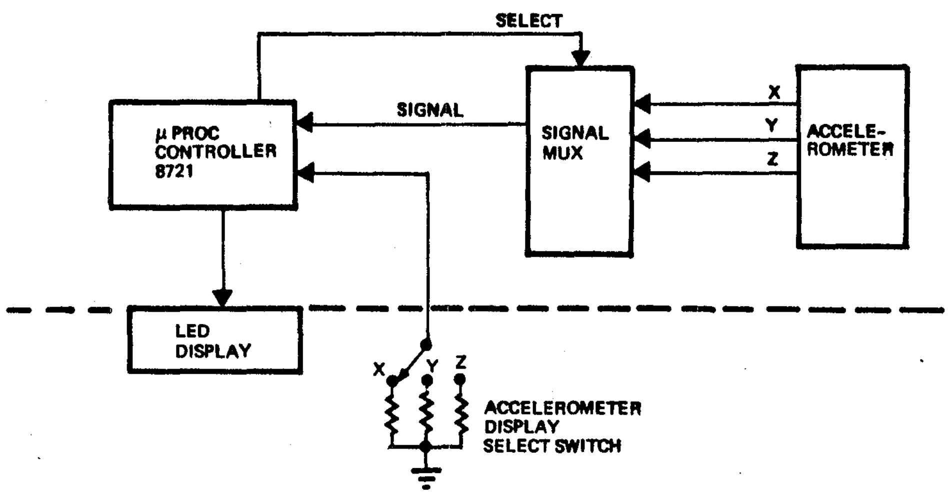


Figure 4.2-2 FREE SURFACE PHENOMENA EXPERIMENT CONTROL

A rough estimate of the experiment power consumption can be made.

Fan	-	34 watts
Motor	-	30 watts
Electronics	-	20 watts
Camera	-	100-170 watts
Total		184-254 watts.

The camera power will be the determining factor in the power budget. Camera film speed must be maintained low enough that the 265 watts is not exceeded. This budget assumes no regulated power supplies which implies that the camera power supply will be stable from 23-32 V.

4.3 EXPERIMENT LAYOUT

Figure 4.3-1 shows the detailed layout. An isometric view of the Free Surface Phenomena Experiment is shown in Figure 4.3-2. The experiment enclosure is similar to that in Figure 4.3-3. The experiment is contained within the volume of a double mid-deck locker which provides space for all the equipment, electronics and controls. The equipment list is in Table 4.3-1. The layout shows the position of all four test cells in the stowed position during take-off and landing. For actual test, the three cells not in the test position are removed to allow working access. The arrangement shown in the layout was designed such that the camera-to-object distance can be optimized for the required FOV and the test cell be located near the front for access and visual inspection. The alternative layout shown has

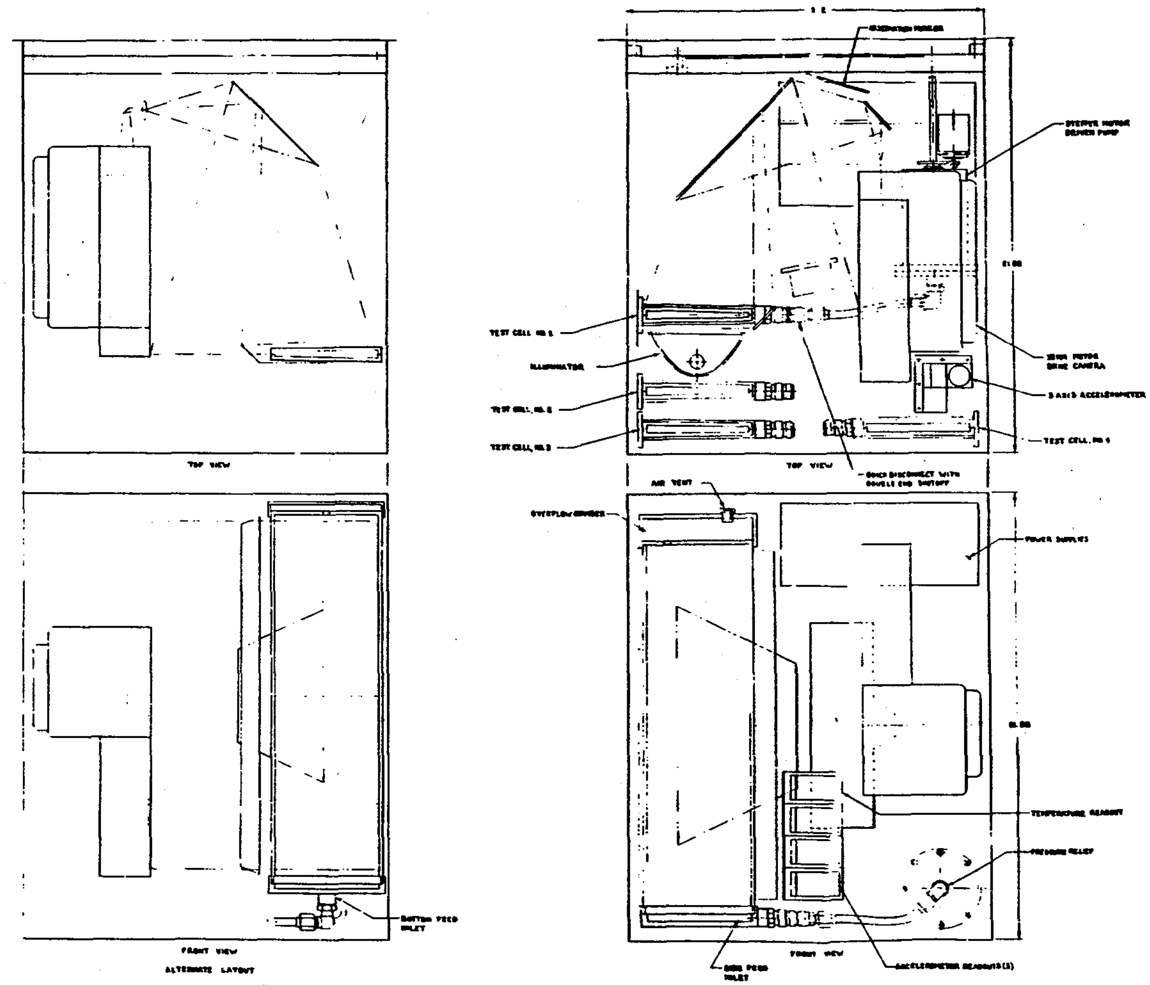


Fig. 4.3-1 FREE SURFACE EXPERIMENT LAYOUT

E 11982 FREE SURFACE PHENOMENA LAYOUT

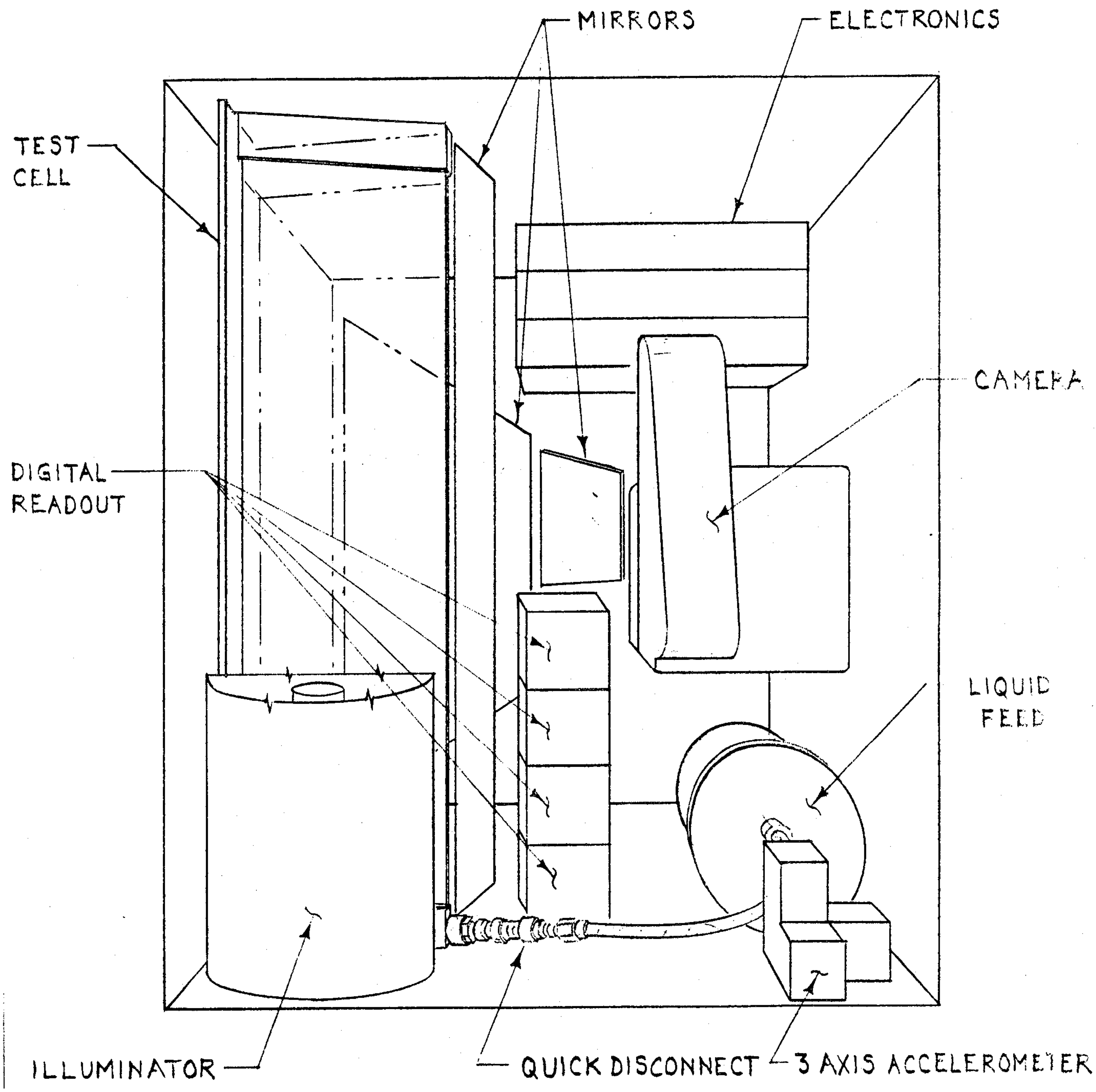


Figure 4.3-2 FREE SURFACE PHENOMENA

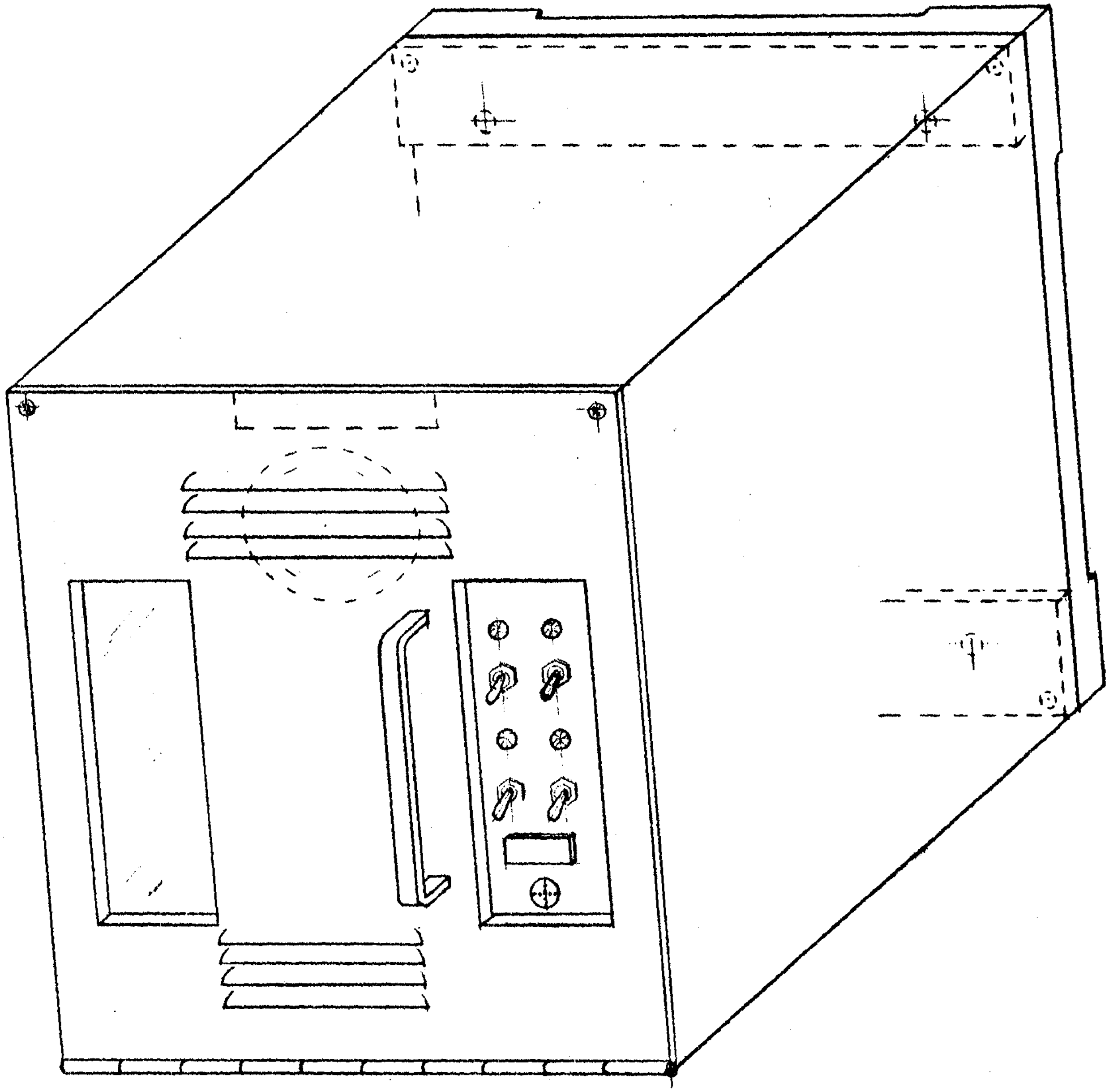


Figure 4.3-3 EXPERIMENT ENCLOSURE

Table 4.3-1

EQUIPMENT LIST

COMPONENT	DIMENSION	VOLUME
Experiment Container (4)	5 cm x 15 cm x 52 cm	3.9×10^{-3} M^3 (each)
Fluid Storage	10 cm x 15 cm	1.1×10^{-3} M^3
Fluid Drive	26 cm long	---
Cine Cmaera	25 cm x 32.5 cm x 8 cm (max)	65×10^{-3} M^3
Illumination	50 cm x 12 cm (half cylinder)	3×10^{-3} M^3
Air Pump	7.6 cm (dia) x 3.8 cm	$.2 \times 10^{-3}$ M^3

basically the same features, the difference being in the feed line connection arrangements and the left/right placement of the test cell.

4.4 WEIGHT ESTIMATE

The weight is estimated based upon the experiment design. The components identified are given in Table 4.4-1. Weight estimates for procured parts are considered fairly reliable. Items that require detailed design such as:

- o The optical components
- o The experiment container
- o Fluid drive assembly
- o Enclosure and door
- o Power supplies

are estimates based upon current design philosophy. As with the Surface Tension Driven Convection Experiment we have utilized the current signel adpator - double adpator plate weights. If lighter weight plates are used a significant weight saving will be realized. The c.g. data in Table 4.4-1 is within the guidelines of Ref. 2.2.

4.5 EXPERIMENT STATUS AND RECOMMENDATIONS

The requirements for the Free Surface Phenomena Experiment reflect the requirements as given in Reference 1.3 and as modified at the conceptual design review. Some requirements are not defined due to a lack of knowledge of the experiment operation parameters. Some of the operational parameters will only be defined after one or more flights.

The experiment meets the STS mid-deck requirements as given in 2.7 for volume, weight and power. The design features for the experiment are given below.

Experiment Volume. The experiment is contained in a double locker volume. There is adequate room for all components. The major considerations in the design were to accommodate the experiment container length and to obtain a maximum FOV, the entire tube length.

FOV. The field-of-view of the entire cell is obtained by maximizing the camera to cell distance. The camera is maintained in the experiment structure to minimize alignment of extraneous vibrations. A 35 mm camera format will allow the entire cell length to be viewed.

Diagnostics. The only requirements, except for the visual observation is that of ambient temperature and of acceleration. These can be measured at the camera using LED's.

Power. The power within the mid-deck operating conditions depending on camera speed.

Unresolved operational questions are as follows.

Fluid Flow. The flow rate will be a critical factor in the experiment operation (Section 4.1.3). The flow rate should be maximized but is dependent upon the pore size that can be used.

Film Speed. film speed should be maximized consistent with the power constraints and available footage.

TABLE 4.4-1 FREE SURFACE PHENOMENA
WEIGHT ESTIMATE

COMPONENT	WT (LBS)	X⊗	Yϕ	Z↔	M_x	M_y	M_z	
Accelerometer	.50	16.88	-9.54	+6.80	8.44	-04.77	3.40	
16mm Camera	14.00	10.00						Alternate
35mm Camera	20.75	11.4	+ .36	+5.74	236.55	7.470	119.105	
Stepper Motor	.65	6.66	-7.60	8.00	4.329	- 4.94	5.20	
Cell 1 (in place)	5.06	13.50	+ .28	-5.52	68.31	1.417	-27.931	
2	5.06	17.24	+ .28	-5.52	87.234	1.417	-27.931	
3	5.06	19.24	+ .28	-5.52	96.747	1.417	-27.931	
4	5.06	19.12	+ .28	-5.58	96.747	1.417	28.235	
Pump	2.16	8.98	-8.36	+6.54	19.397	-18.058	14.126	
Light	4.50	15.24	0	-5.58	68.58	0	-25.11	
Fan	1.00	19.265	+8.50	0	19.265	8.50	0	
Power Supply	11.62	5.08	+8.46	+3.54	59.030	98.305	41.135	
Mirror #1	.06	3.80	- .36	+3.72	- .228	- .022	.223	
#2	1.18	4.88	- .36	-4.00	5.758	- .425	- 4.27	
#3	.31	13.30	- .36	-2.30	4.123	- .112	- .713	
Single Adapter	13.00	.375	0	0	4.875	0	0	
Double Adapter	12.50	1.187	0	0	14.838	0	0	
Q Disconn - Red	.084	13.50	-9.87	0	1.134	- .82	0	
Q #1	.103	13.50	-9.76	-1.50	1.391	- 1.005	- .155	
#2	.103	13.50	-9.76	-1.50	1.391	- 1.005	- .155	$\bar{x}$ = 9.856
#3	.103	19.12	-9.76	-1.50	1.969	- 1.005	- .155	$\bar{y}$ = .717
#4	.103	19.12	-9.76	-1.50	1.969	- 1.005	- .155	$\bar{z}$ = 0.837
Readouts (4)	.336	11.70	-5.70	+ .22	3.931	- 1.915	.074	
Hose and Fittings	.15	13.00	-9.34	+4.00	1.950	- 1.401	.60	
Enclosure	22.119	10.885	0	0	240.765	0	0	
Door	4.834	20.265	0	0	97.961	0	0	
E_m =	116.405				1147.298 x=9.503 y= .717 z= .837	83.503	97.453	

Cell Material/Constitution. Cell material must be compatible with the fluid and must give the appropriate contact angle. The smoothness and angle sharpness must be quantitatively defined.

4.6 SAFETY

The Hazard Reports and Safety Matrix are included in Appendix E. There are no obvious safety issues except the selection of the fluid. The fluid must be compatible with STS operations. The use of silicone oil will probably be acceptable. Fluorocarbons may be allowed since there are minimal heating sources at the experiment.

APPENDIX A

Fluid Transfer In Zero Gravity

This appendix describes an experiment concept derived during the performance of this study. The experiment investigates liquid handling techniques in low gravity. An appendix derives the modified Weber number discussed in the text.

LIQUID TRANSFER INTO AN OPEN CONTAINER UNDER ZERO-GRAVITY

The objective of this experiment is to investigate the feasibility of a liquid handling technique under zero-gravity conditions which may be useful in many scientific experiments and in other routine operations. More specifically, this experiment will provide experience which may enhance the success probability of the Fluid Physics Experiments which are presently undergoing preliminary design stages. The problem addressed is how to fill an open vessel (e.g. a cup) with a liquid in such a way that the liquid is collected on a predetermined surface (such as the conventional "bottom" of the cup). Under zero-gravity conditions a fluid cannot be simply poured; it has to be forced in a given direction. No guarantee exists, however, that the liquid will remain in contact with the surface upon which it is forced. In fact, the liquid may splash, breakup to droplets, and detach from the surface. Simple minded fluids experiments performed on board Skylab, and more recently aboard the Shuttle, have demonstrated interesting and often unexpected behavior.

The proposed experiment is extremely simple, it does not require any Shuttle interface, it is self contained, and can be performed by one crew member, while another crew member photographs the procedures with a hand held video camera. The technique involves forcing a liquid (water) into a cup through a porous element (see illustration 1). Under the correct conditions of fluid momentum, wetting angle, and surface tension, the fluid is expected to adhere to the porous bottom and the walls of the vessel allowing the vessel to be filled to a desired level.

Admittedly, the experiment is simple and will not resolve all questions which come to mind. The effect of surface material or liquid properties, are of secondary interest. The main objective is to perform an experiment which will require only a minimum level of funding, will have no safety or special planning requirements and will provide useful scientific and engineering information*. The proposed experimental set up, shown in illustration 2, made up of lucite, will be stored in one of the mid deck stowage lockers. It will be removed from the locker for testing and returned upon completion of the test. The data will consist

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* It is believed that a drop tower, KC-135, or Lear Jet experiments will be too costly due to the automation requirements.

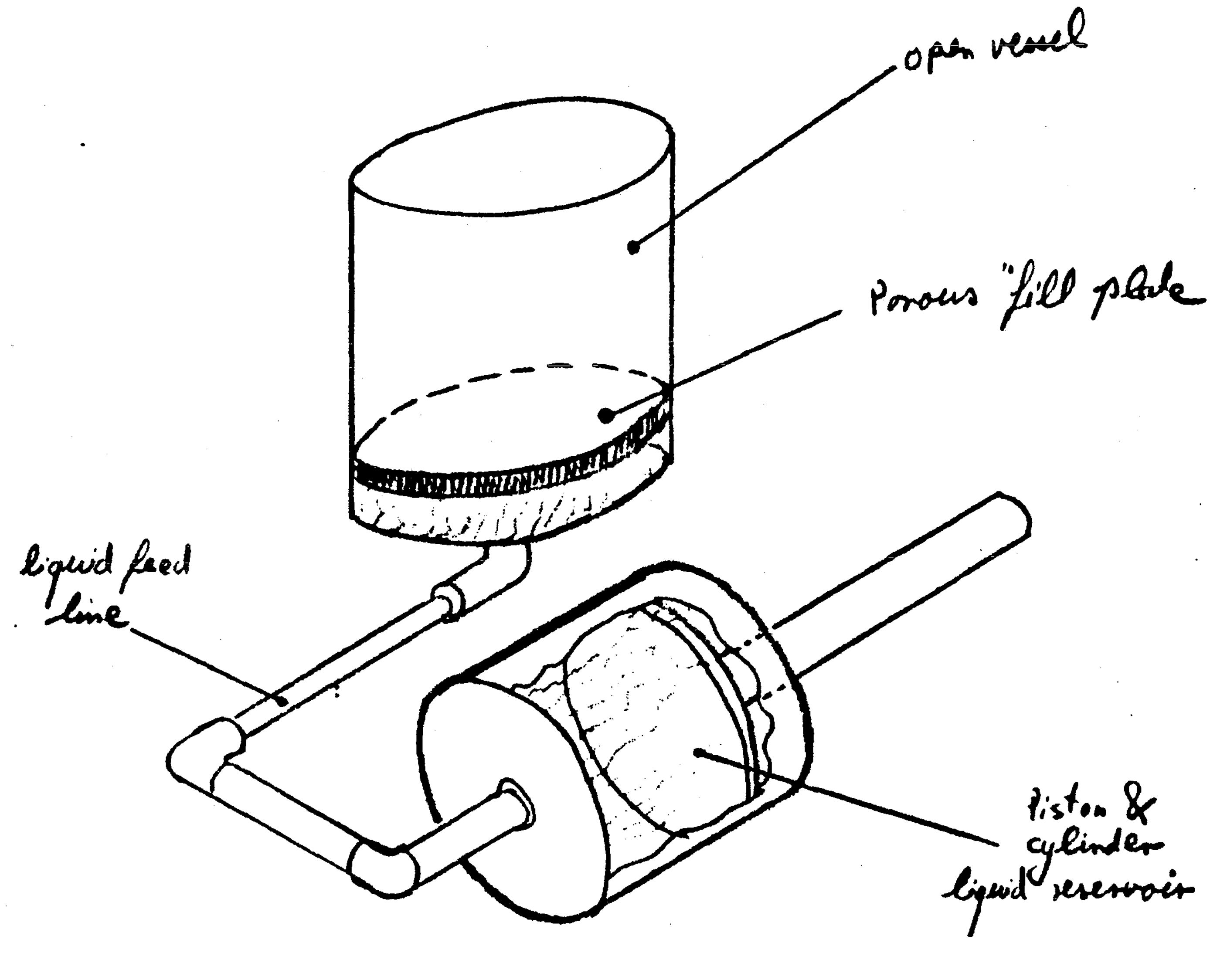

Illustration 1.

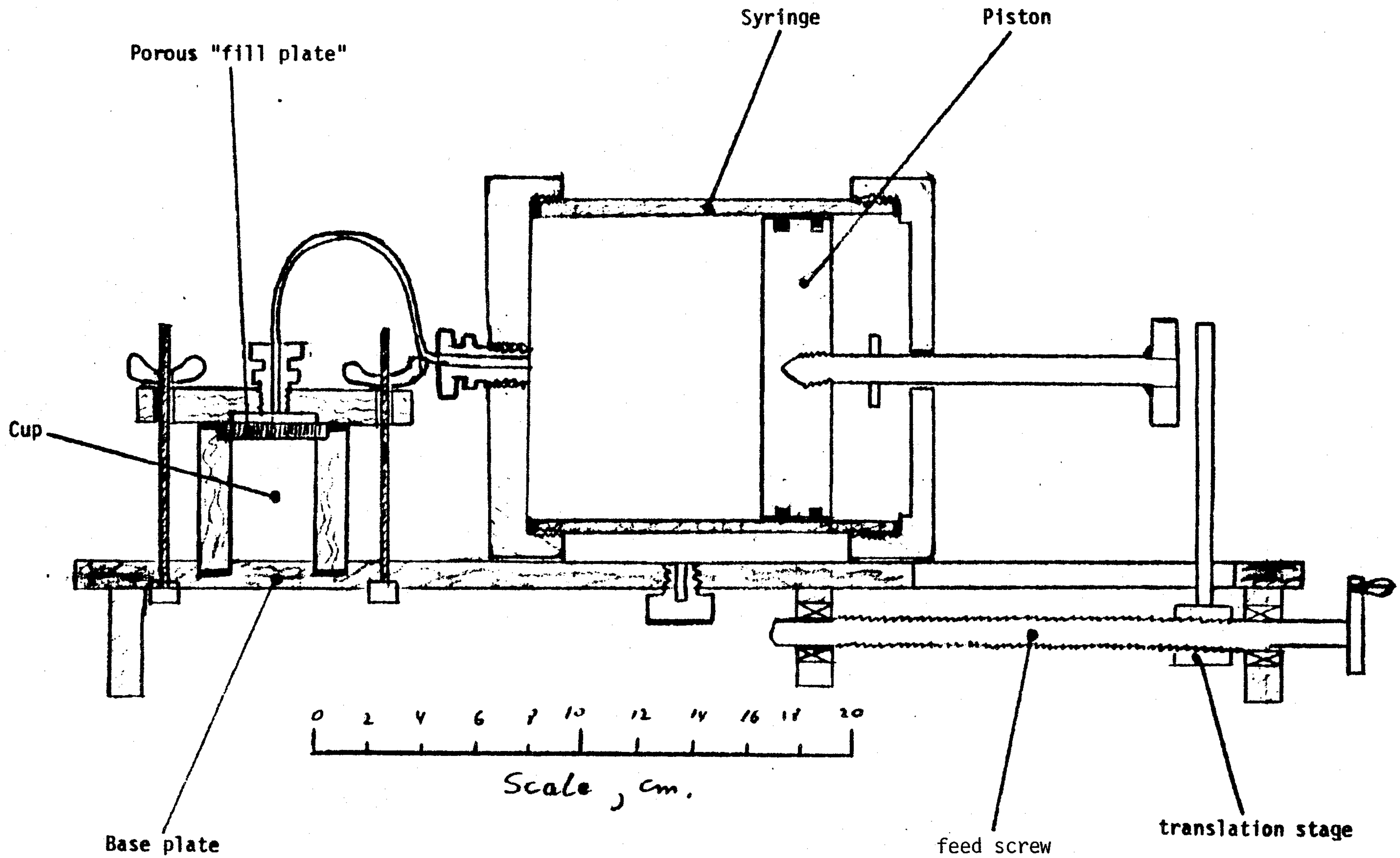

Illustration 2: SCHEMATIC OF THE LIQUID FILL EXPERIMENTAL SET UP.

of the recorded video tape of the experiment. The attached appendix describes in simple engineering terms the considerations leading to the proposed design.

THE EXPERIMENT DESCRIPTION

The experiment consists of a one liter syringe manually driven via a translation stage and a feed screw, and a 60 cm^3 cup with a replaceable "feed plate". The cup, syringe and support plate are made of lucite allowing direct photography either through the side of the cup or through the support plate.

The test procedure starts by the removal of the set up from the stowage locker and positioning on a "test bench" and connection of the feed line between the syringe and cup. Feed rate is determined by how fast the screw is turned. At a ¼ revolution per second, the feed rate is approximately 1.2 cm^3/sec (using a 64 threads/inch screw). The first trial should consist of slow filling of the cup, to about 1 cm depth over the "fill plate" (about 20 cm^3). The cup is then removed, the water in it wiped with a rag or a sponge and the cup reinstalled (using three wing nut screws). The experiment is then repeated at a different feed rate. The procedure will be repeated for several types of "fill plates" consisting of various solidity sintered metal elements, screen mesh, and honeycomb. All the "fill plates" are kept in a specially designed storage within the test setup. The rag or sponge used to wipe the cup dry between the experiments is also stored as part of the setup.

The detailed test matrix and the specific "fill plates" information will be prepared during the detailed apparatus design.

APPENDIX

Illustration 3 shows a liquid emerging through a pore of a porous element. The simple force balance states that the momentum of the emerging liquid jet should be smaller than the restraining force of the liquid tension (adhering to the wall).

$$\rho V^2 \frac{\pi d^2}{4} < \sigma \pi d$$

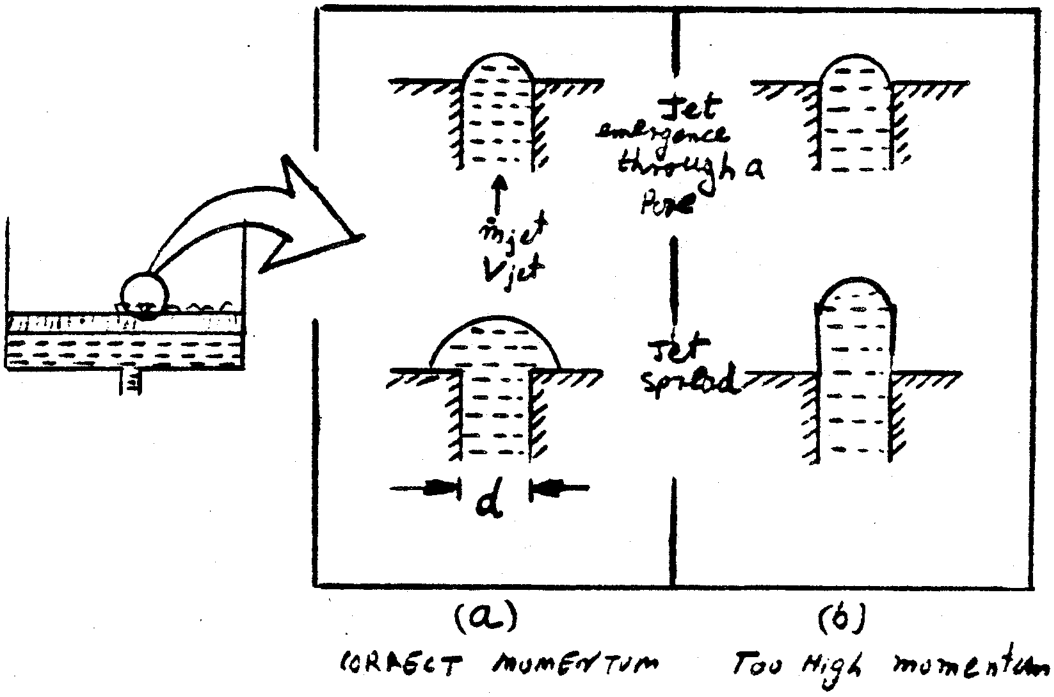

Illustration 3.

Once the liquid covers the "fill plate", the jets penetrate the bulk of the liquid and dissipate their momentum in a conventional maner (due to viscosity), but the bulk of the fluid has to resist and absorb the total

momentum of the jets (illustration 4).

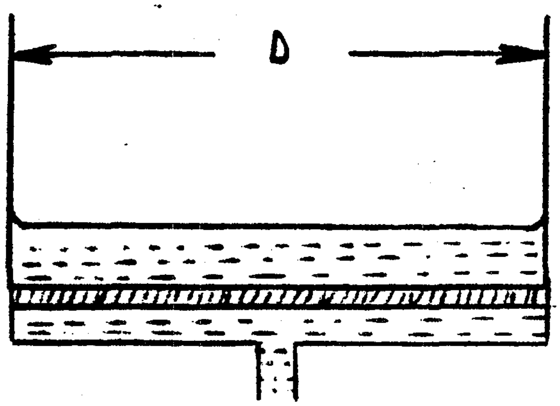

Illustration 4.

$$\rho V^2 \frac{\pi D^2}{4} \alpha < \sigma \pi D$$

where α is the fraction of open surface area of the "bottom" plate.

In both cases, the analysis yields

$$We = \alpha \frac{\rho V^2 d}{\sigma} < 4$$

or a modified Weber number smaller than 4.

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APPENDIX B

Surface Tension Driven Connection
Flow Visualization

This report is a result of work performed at Case/ Western Reserve University for Dr. Y. Kamotani by a student, Tom Kerslake. The report includes studies on flow visualization. The report defines fluids and particles that are applicable for the experiment. It also contains information on heater power required, temperatures and flow patterns.

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Appendix B

SURFACE TENSION DRIVEN CONVECTION FLOW VISUALIZATION

by

Tom Kerslake

Summer Project Advisor: Dr. Y. Kamotani

Department of Mechanical and Aerospace Engineering
Case Western Reserve University

June 14 - September 9, 1983

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ABSTRACT

The purpose of this project is to find optimum conditions for flow visualization of surface tension driven convection flow. These conditions include fluid type, particle type, heater geometry and corresponding temperature gradient output, and illumination system. Dimethyl silicone fluid was predetermined to be a good working fluid (ref. 3), and several different viscosities are tested. Samples of 10 and 20 centistokes are found to be best suited. Particle size ranges from 0.3 um to 5 um, with three different types of particles tested. Alpha-Alumina particles (1.0 um) are found to be the best suited and are used at a concentration of 3.0 - 6.0 mg per liter in 20cs fluid and 5.0 - 7.0 mg per liter in 10cs fluid (ref. 2). Two different heaters are used at several power imputs and heights above the fluid surface. Heater 2 (see Heating System, pg. 4) is found to be the superior heater and it creates an optimum convection flow at a 5.0mm height and a 17 watt power input. The proper laser for illumination was also predetermined. A compromise between power limitations and effective particle illumination leads to the use of a 5 milliwatt Helium-Neon laser (ref. 1).

ACKNOWLEDGEMENTS

I would like to thank Dr. Yasuhiro Kamotani for his guidance and ideas regarding this project. I would also like to express my gratitude to Mr. Mike Marhefka for his help and advice in building experimental apparatus. An lastly, my thanks go to Sudin Manja for his input into this project.

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INTRODUCTION

This experiment is designed to further the existing knowledge of surface tension driven convection flow. Although this phenomenon often has negligible effects on fluids in normal earth-like conditions, it becomes a major contributing factor in how fluids behave under near zero-gravity conditions. This behavior is of great interest to us since the advent of Space Shuttle operations and hence, the ease at which we can obtain a near weightless environment (accelerations approximately 10^{-5}g, ref. 4) in low earth orbit. Many manufacturing processes can be greatly improved in space. Crystal growth, for example, can be done without the use of a container (e.g. floating zone technique) and therefore, eliminate the contamination and the imperfections associated with it. The weightless environment also minimizes imperfections due to the natural convection involved with fluids here on earth. Thus it is important that this surfact tension driven flow is studied and understood so that space manufacturing and production techniques may be utilized to the fullest.

An important part in understanding surfact tension driven flow comes from observation and photographic technique. Therefore, a system that can be visually studied is of great value. This project concerns itself solely with optimizing the conditions for flow visualization. This consists not only of finding the proper fluid, tracer particles and optics, but also of generating an acceptable flow. Since surface tension flow is heat induced, a sufficient temperature gradient must be maintained across the

surface of the fluid within the test section. This necessitates investigation into different heat sources, heater configurations, power requirements and limitations. For this project, a nichrome wire heating coil is used and the final power limits are dictated by the capacity of self-contained power units designed for use in space. This experiment attempts to optimize the heating system, as well as all the elements involved in a flow visualization, given the known restrictions and limitations.

DESCRIPTION OF EXPERIMENTAL EQUIPMENT

Test Section

The test section is made in part from tubular plexiglass stock, 10cm outside diameter, 0.3cm wall thickness, and 5cm in height (ref. 3, fig.1). This cylinder is bonded to a plexiglass base plate, 15cm square and 0.6cm thick. An aluminum base plate, 15cm square, 0.3cm thick, was also used. As the aluminum plate's thermodynamic properties inhibited the proper flow patterns, it was not used for further testing.

The motivation for designing the test section in this manner comes from the fact that cross sections of fluid in any plane may be studied, assuming the heat inducing the surface tension flow is symmetrical with respect to the test section.

Fluids

Silicone oil was predetermined to be the working fluid for this type of experiment (ref. 3). It is clear, safe, easy to handle, and relatively insensitive to contamination. This last property is important since contaminants from the air or test section may cause concentration gradient type counterproductive flow (ref. 4). The specific type of silicone oil used in this case is dimethylpolysiloxane. Viscosities of 10, 20, 25, 50, 100 centistoke are used. Both General Electric and Dow Corning fluids are tried, with final data taken using Dow Corning-200 10cs fluid and General Electric SF96-20cs fluid. Fluoroinert Electronic Liquid FC-77 (3M Company) was also tried but not used. This liquid was volatile enough that evaporation alone caused a surface tension flow without any heat imput (ref. 1). The liquid also had little viscosity and would not suspend particles.

Particles

An ideal particle would have the following characteristics: small enough not to impede the natural convective flow of the fluid, reflective enough to be easily seen and photographed and finally, a density such that the particle would remain suspended in the fluid. Three such particle types are used: (Buehler) aluminum oxide - 3.0µm, (Buehler Micropolish) alpha Alumina - 1.0µm, and (Polysciences, Inc.) glass beads - 1 to 5µm. Each type particle is within the desired size range of 1.0 - 5.0µm (ref. 1). Several other particle types were tried and not used because the silicone oil would not suspend them. Examples are copper shots (0.5mm), copper beads (80-100 mesh), and Dylite F-40-C-Beads (0.5mm).

Heating System

Requirements for the heating system are that the heater approximate a point heat source (to produce a decreasing temperature gradient from the center of the test section outward), radiate heat symmetrically, use a minimum of power, and maximize the temperature gradient across the liquid surface, thereby maximizing the surface tension flow. Two nichrome wire (diameter-0.9mm) coil heaters are used with both coils having ceramic cores (fig.2). Heater 1 has a coil diameter of 1.7cm and 13 coils spaced approximately 1mm apart. It has a resistence of 1.7 ohms at room temperature. Heater 2 has a coil diameter of 0.6cm and four coils spaced approximately 2mm apart. It has a resistence of 0.5 ohms at room temperature. Each heater is connected to a Powerstat variable transformer, which is in turn plugged into line voltage. In addition, a 15 volt AC voltmeter (reading accuracy to 0.1 volts) and

Figure 1 : Test Section

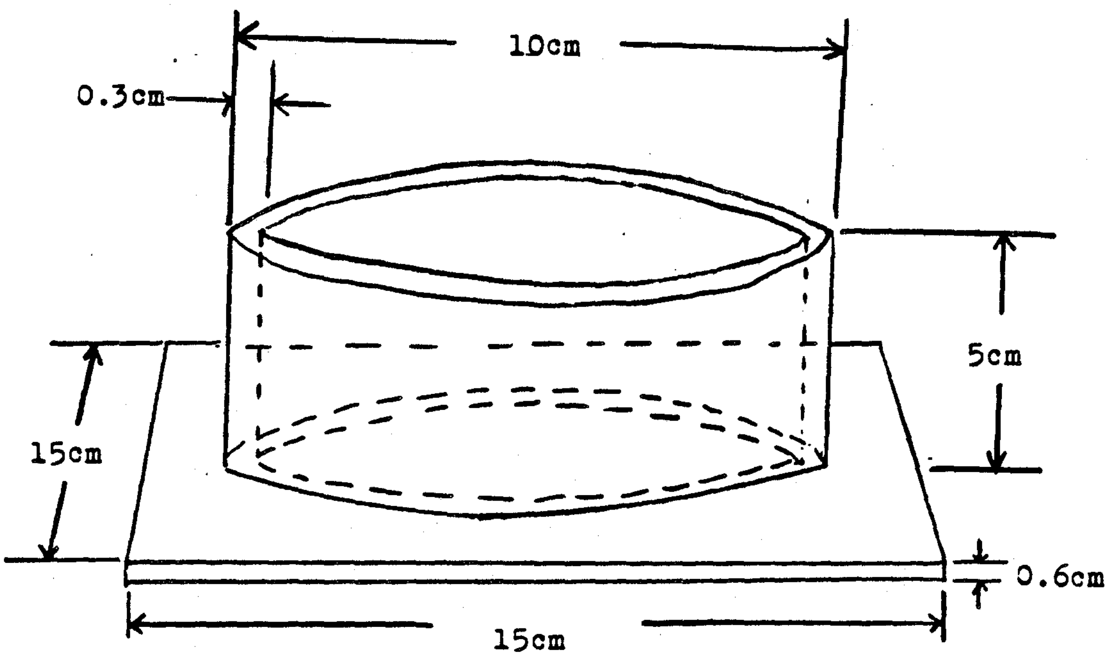


Figure 2 : Heater Coils

Heater 1

Heater 2

a 10 amp AC ammeter (reading accuracy to 0.1 amps) are connected into the heating coil circuit to monitor power imput (fig. 3). For heater placement, the ceramic core is attached to a vertical positioner, which may raise or lower the heater above the liquid surface by means of precision screw thread advancement.

Optical System

The illumination source is provided by a Spectra-Physics Stabilite 5mW Helium-Neon Laser (Model 120s) using a Spectra-Physics Laser Exciter power source. The 5mW laser was chosen to comply with the power requirements for a space experiment (ref. 1). The laser beam is spread into a plane (approximate thickness of the plane is 1mm) by a cylindrical lens, 4.8 x 5.3mm in size and having a 11mm focal length. The plane of light passes through the test section with an approximate thickness of 1.5mm.

Photography

Photographs are taken using a Graphex Polaroid land camera and bellows with a Graphex Optar f/4.7 135mm lens. The camera is positioned perpendicular with respect to the laser plane with a distance of 23.5cm between the lens and the laser plane. The photographs are shot using only the laser light (room lights are turned off) and thus require high-speed film. Black and white Polaroid film (type 47) ASA 3000 is used with an aperature size f=8 and a 3 second shutter speed or f=11 and a 3.5 second shutter speed. The prints are developed 25 seconds before peeling off the final photograph. All shots are taken at room temperature, 78°F.

Figure 3 : Heater Circuit

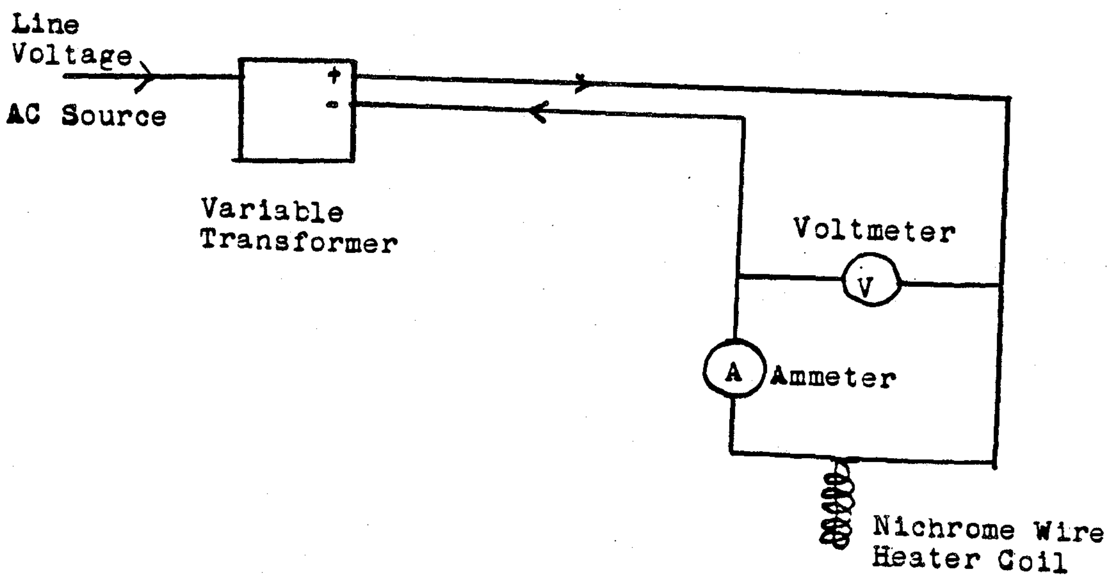
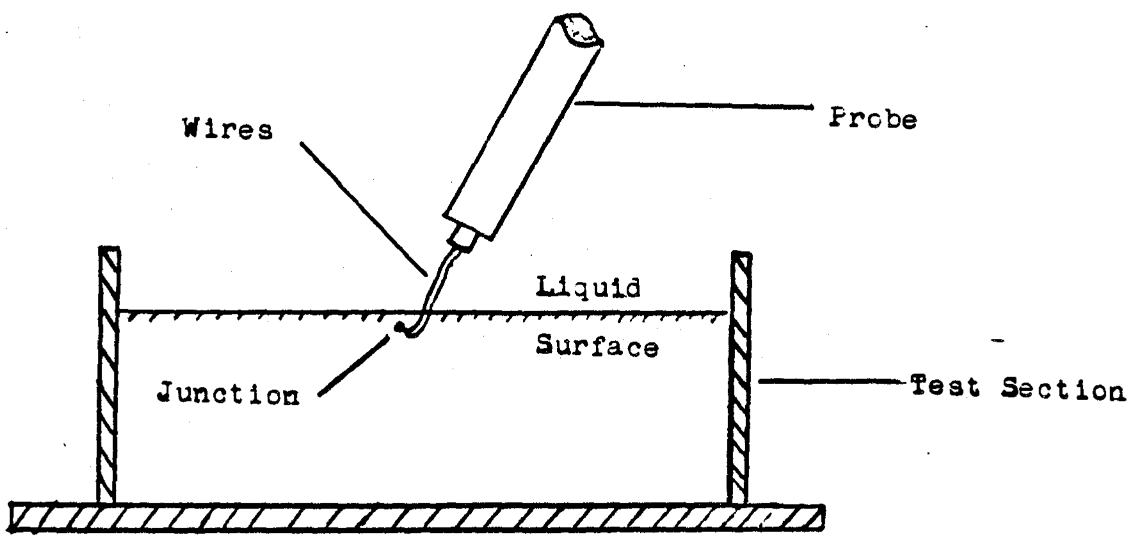


Figure 4 : Thermocouple



Thermocouple Probe

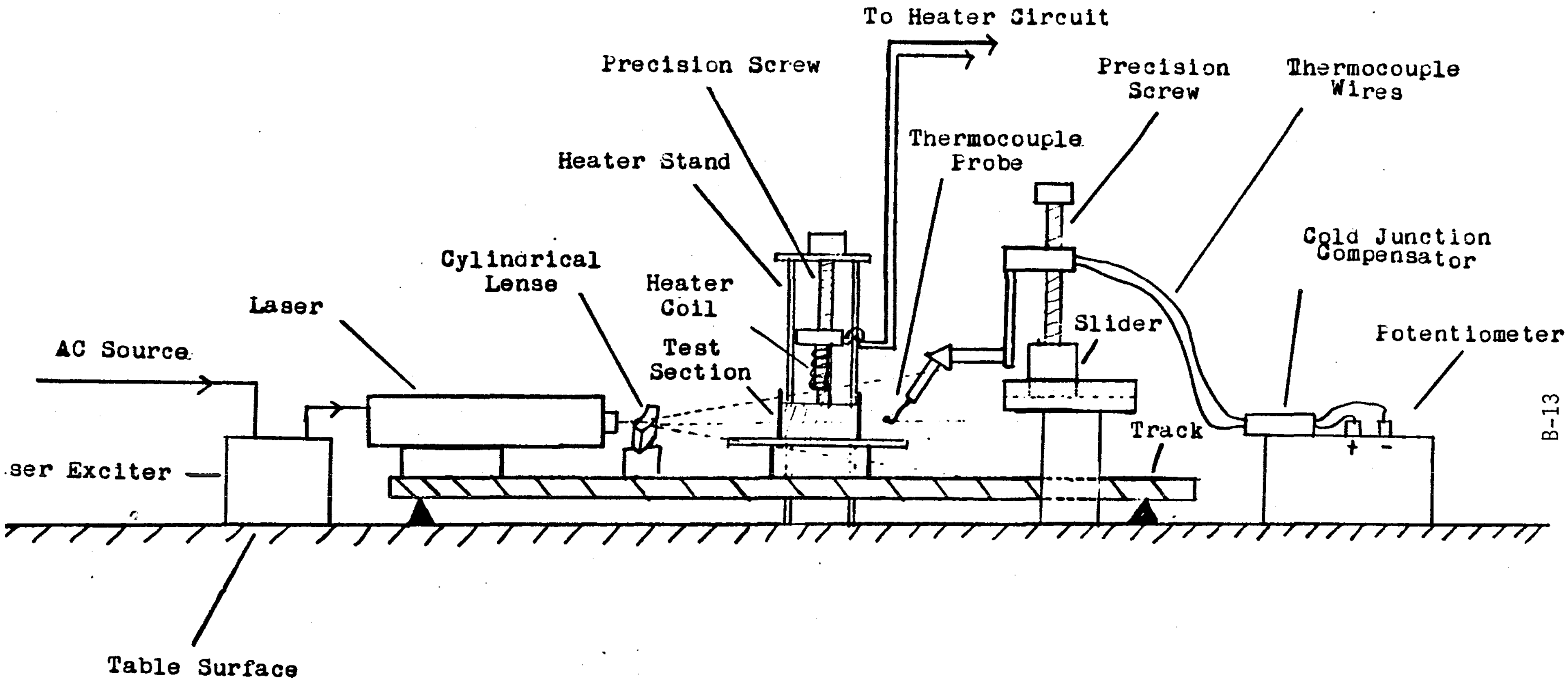
Temperature measurements across the liquid surface are taken with a Type T, Copper-Constantan thermocouple. The bulb is small enough (0.3mm) and the wires are thin enough (0.15mm) not to subtantially disturb the natural flow of the fluid. The thermocouple wires are formed into the shape of a hook to allow the small exposed portion of the wires to be submersed under the liquid surface (fig. 4). This is done to minimize the error introduced by exposing the uninsulated part of the thermocouple wires to direct heater radiation. Errors introduced by conduction along the thermocouple wires are not considered, assuming the ΔT across the exposed region of the wires is not able to drive a substantial heat flow to or from the junction. The thermocouple itself is contained within a probe attached to a three degrees of freedom positioner. Readings are taken using an Omega-CJ cold junction compensator connected to a Leeds and Northrup millivolt potentiometer -cat. no. 8686 (reading accuracy to 0.001mV). Temperatures may be determined using Omega, Inc. standard reference tables.

Experimental Set-Up

The laser, lens and test section are lined up and positioned on a track. The heater positioner stand is placed beside the test section and is centered using the laser beam as a reference. The heater height is adjusted from the liquid surface by precision screw thread advancement. Knowing the lead of the thread, enables a specific height to be reached by a given number of screw turns. The thermocouple positioner stand is also placed beside the test section and the junction is centered by use of the laser beam. The thermocouple junction is then

adjusted downward (again by precision screw thread advancement) until it is just submersed. Readings are taken at measured locations radially outward from the center of the test section by means of a calibrated slider (one degree of freedom of the positioner). See figure 5. The camera is placed in front of the test section (facing perpendicular to the track) on the same table as the track is resting.

Figure 5 : Experimental Set-Up



DESCRIPTION OF EXPERIMENTAL PROCEDURE

Particle Determination

The test section is filled with a given amount of silicone oil (~100ml) of known viscosity using a burret. A given amount (~0.5mg) of the particles is weighed out to be tested. The particles are mixed into the silicone oil and the test section is illuminated with the laser plane. The heater is then positioned and adjusted to the desired height above the liquid surface (~5mm) and a given power setting (~15 watts) selected. Observations and comments with respect to the visibility of the particles, are recorded and a photograph taken. The procedure is repeated keeping everything constant except the type of particle. After all particles have been tried, results are compared.

FLUID VISCOSITY DETERMINATION

One-half (0.5) mg of the best suited particles (from Particle Determination) are weighted out and then mixed into 100ml of the known viscosity silicone oil in the test section. The test section is illuminated with a laser plane and the heater positioned 5mm above the liquid surface, at a 15 watt power setting. Observations and comments with respect to the speed of fluid motion and how well the particles suspended in the fluid are recorded. A photograph is taken. The procedure is repeated changing only the fluid, until all viscosities of silicone oil have been tried. Results are compared.

Although the power could conceivably be varied in this part of the procedure (to increase the convective flow for photographic purposes), it is best if the most free flowing fluid is chosen for power considerations. Yet a compromise must be reached between

the fluidity of the liquid and its ability to suspend particles, since the less viscous, free flowing liquids tend to suspend less particles.

Particle Concentration Determination

A concentrated mixture of 5mg of the test particle and 10ml of the test fluid is prepared. The test section is filled with 100ml of this same fluid. By pipette, 0.2ml (equivalent to 0.1mg of particles) of the concentrated mixture is transferred into 100ml of fluid and stirred. The test section is illuminated and the heater postioned 5mm above the liquid surface at a 15 watt power setting. Observations and a photograph are made. The pipetting procedure is repeated until the optimum particle concentration has been determined. Since there is approximately one additional milliliter of fluid added and there exists an error of approximately $\pm$ 1.0ml (fluid adhering to the walls of the burret) when measuring out the original 100ml of fluid, the final volume of fluid is subject to a tolerance of $\pm$2.0ml. This tolerance is acceptable within the desired experimental accuracy.

Heater Power and Configuration Determination

The test section is filled with the optimum fluid-particle mixture and the heater positioned in the center of the test section abpve the liquid surface a determined distance. The heater is turned on to the desired power setting. The thermocouple junction is positioned in the center of the test section (directly below the heater), just beneath the liquid surface. The thermocouple reading is monitored every five minutes until equilibrium is reached (approximately 1 hour). The reading is now recorded and the thermocouple repositioned radially outward 0.5cm (in some cases,

distances of 0.25cm are used). After five minutes, this reading is recorded and the power level is checked. This procedure continues until the thermocouple junction is 3.0cm or 4.0cm away from the center starting point. After all the readings have been recorded, a photograph is taken and the heater height and power values noted. This procedure is repeated using various power imputs, heater heights, and two different size heaters.

RESULTS AND CONCLUSIONS

The results are presented, section by section, as each experimental part was conducted. The nature of the results is both qualitative and comparative. Therefore, what is discussed is sometimes in terms of an optimum range as opposed to the optimum.

Particles

The best particle type was found to be the Buehler alpha-Alumina micropolish particles. They were easy to measure and to work with. Their 1µm size enabled them to flow freely with the fluid. Yet they were large enough and reflective enough to be seen very well, both by the naked eye and on Polaroid film. The alpha-Alumina particles suspended well in the 20cs silicone fluid and satisfactorily in the 10cs silicone fluid. In the less viscous fluid, approximately 50% settling would occur over a 24 hour period.

The aluminum-oxide particles (3.0µm) suspended very well in the silicone fluid. The one drawback with these particles is that they do not handle very well and are not easily measured. The particles would stick to all surfaces (paper, glass, metal) when they were being weighed and transferred leaving behind a light film of powder. This light film is a significant amount of mass when measurements of magnitude 10^{-4} grams are being taken. The aluminum-oxide particles appear very much like the smaller alpha-Alumina when photographed, yet the smaller particle would ultimately be desired for its flow characteristics.

The glass beads that were used in this experiment were manufactured in a given size range; namely, from 1µm to 5µm.

Visually, they appeared similar to the other two types of particles, but photographically their appearance was nonuniform. Bright, full particle traces, medium particle traces and very faint, hazy particle traces are located about the illuminated plane of fluid in the photograph. This leaves more or less a skeletal convection flow pattern that is difficult to analyze. The glass beads did suspend and flow in the silicone fluid adequately. Photographs of the glass beads, as well as the aluminum-oxide and alpha-Alumina particles are shown in fig.6 .

Fluids

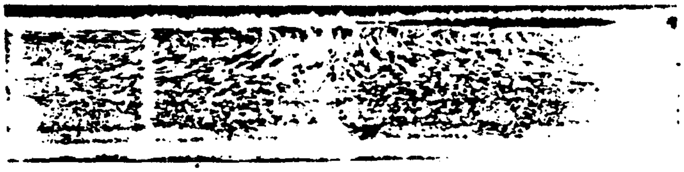
Silicone fluid of 10cs and 20cs viscosity were found to exhibit acceptable convective flow. Obviously, the 10cs fluid convected better than the more viscous 20cs fluid. Yet a compromise must be met between the need for fluidity and the need for a damping factor sufficient to handle the minor vibrations the fluid will experience in a zero-gravity experiment. The higher viscosity fluids (25cs, 50cs, and 100cs) displayed very sluggish convective flow. Increased power input to the heater would increase the convective flow, yet power requirements should be minimized to avoid excess heating of the test section.

As noted earlier, both General Electric and Dow Corning silicone fluids were used. There was no perceivable difference between the two with respect to what was done in this experiment. Availability determined which brand of fluid was used.

Particle Concentration

The optimum particle concentration can be obtained at different concentration values. Depending upon what the researcher would ultimately like to gain from the convective flow photographs, a range of different concentrations would be desired according to the specific use in mind. For the purposes of this

Figure 6 : Particles



alpha-Alumina
Particles
1 µm

aluminum-oxide
3 µm

glass beads
1 µm-5 µm

report, particle concentration for flow visualization is said to be optimum when the flow patterns are most clearly discernable and differentiated, visually and photographically (ref. 2). Particles should also appear as individual bright points of light upon being illuminated. Categories, based on four particle concentration levels, will be specified: sparse, light, medium, and high (ref. 2), fig. 7. The way the particles are seen varies somewhat between direct visual observation and what the camera photographs. Therefore, the evaluation of the particle concentration also states whether it is a visual observation or a photographic one.

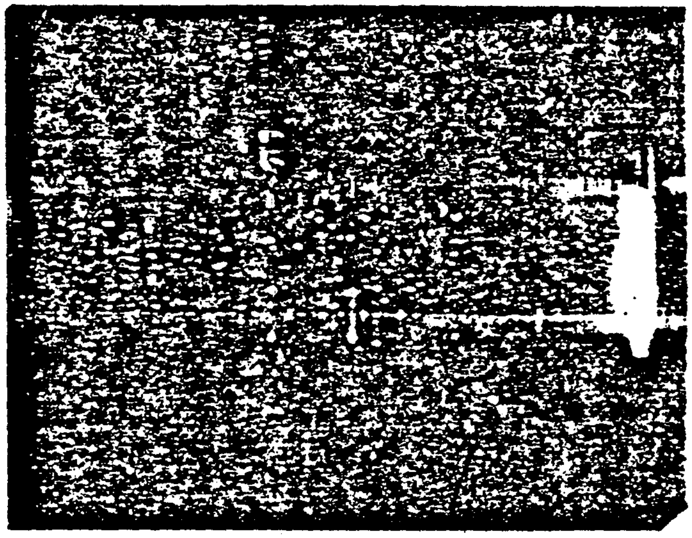
The optimum particle concentration was 5.0-7.0mg of particles in 1.00 liter of 10cs silicone fluid and 3.0-6.0mg of particles in 1.00 liter of 20cs silicone fluid. Detailed results are shown in data table 1 #. Photographs are shown in fig. 8.

Heater Power and Configuration

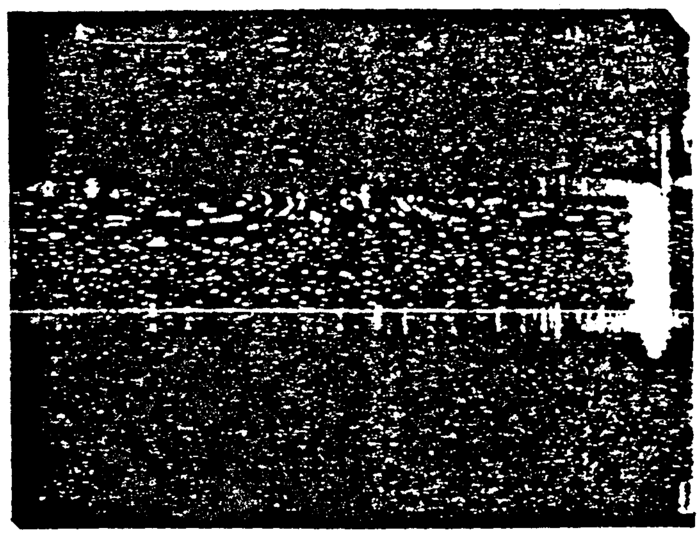
Temperature gradient graphs were made for each different heating condition. Temperatures were plotted against the position (relative to the center of the test section) at which the temperature measurement was taken to produce the characteristic temperature profile for that given set of conditions. On these graphs, the negative sloped portion of the profile represents the temperature gradient inducing the surface tension convective flow. The positive sloped portion of the profile works to counteract the original convective flow. Yet the original convective flow dominates since the counteractive temperature gradient acts upon a relatively small region ($\approx \pi D^2/4$ cm^2, D=diameter of heater coils: 0.6, 1.8cm) of the entire liquid surface area ($\approx 25\pi$cm^2). The ideal temperature profile would be approximated by a negatively sloped line (fig.9).

Figure 7 :Concentration Levels

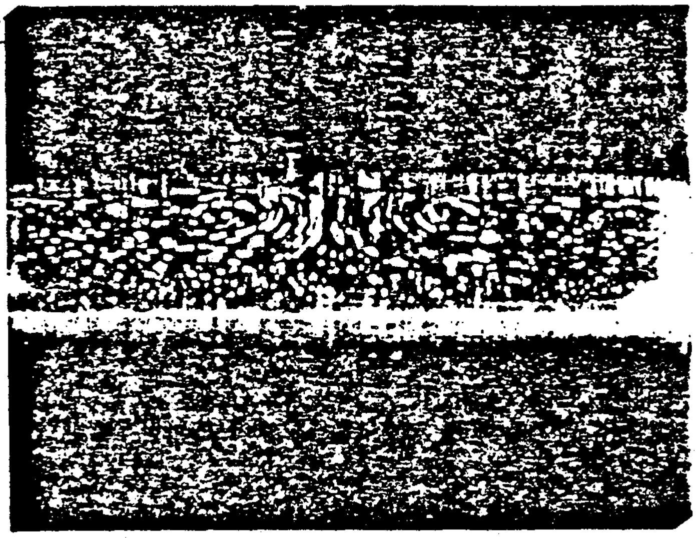
Sparse Concentration



Light Concentration



Medium Concentration



High Concentration

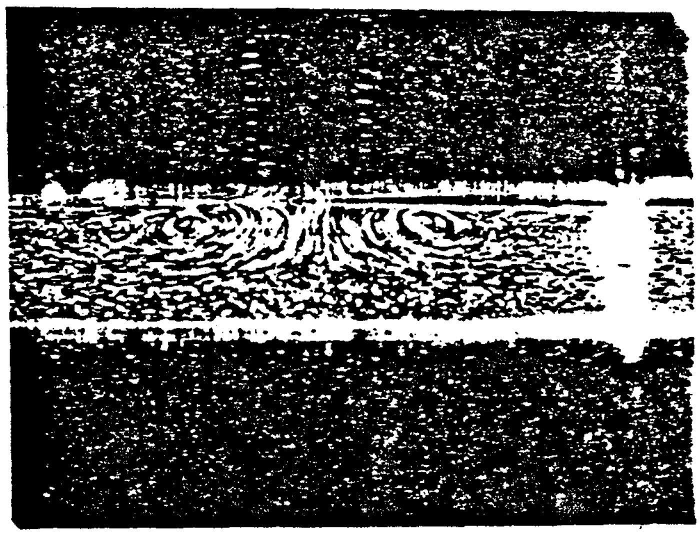
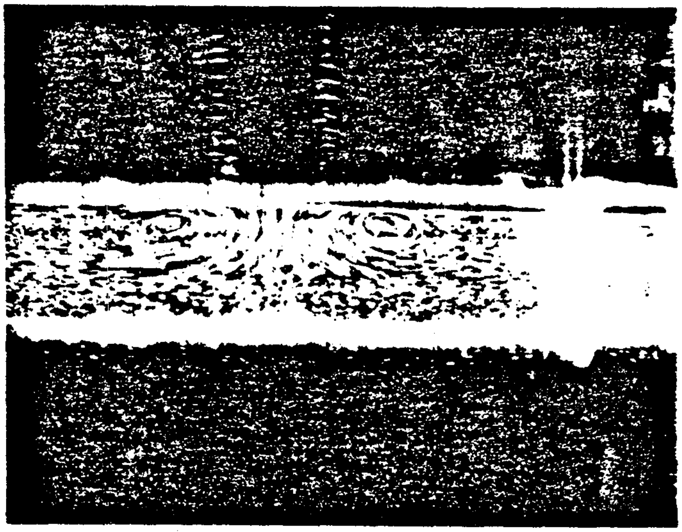


Figure 8 : Optimum Particle Concentration

alpha-Alumina 0.60mg/100ml 10cs fluid



(Note: 100ml volume is subject to a ±1ml tolerance)

alpha-Alumina 0.30mg/100ml 20cs fluid

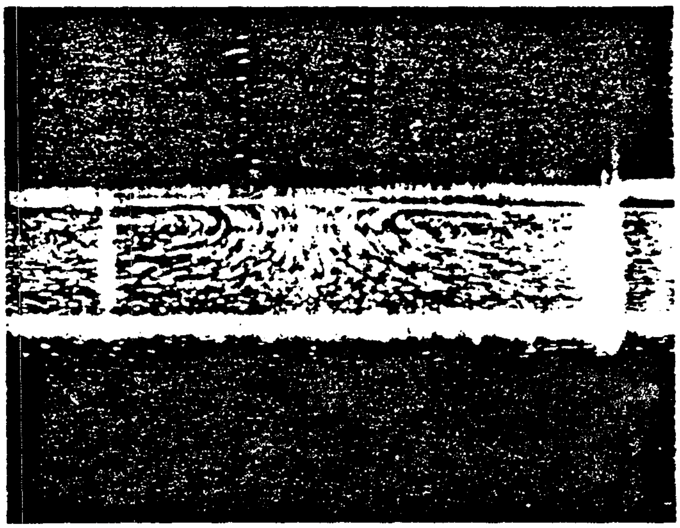
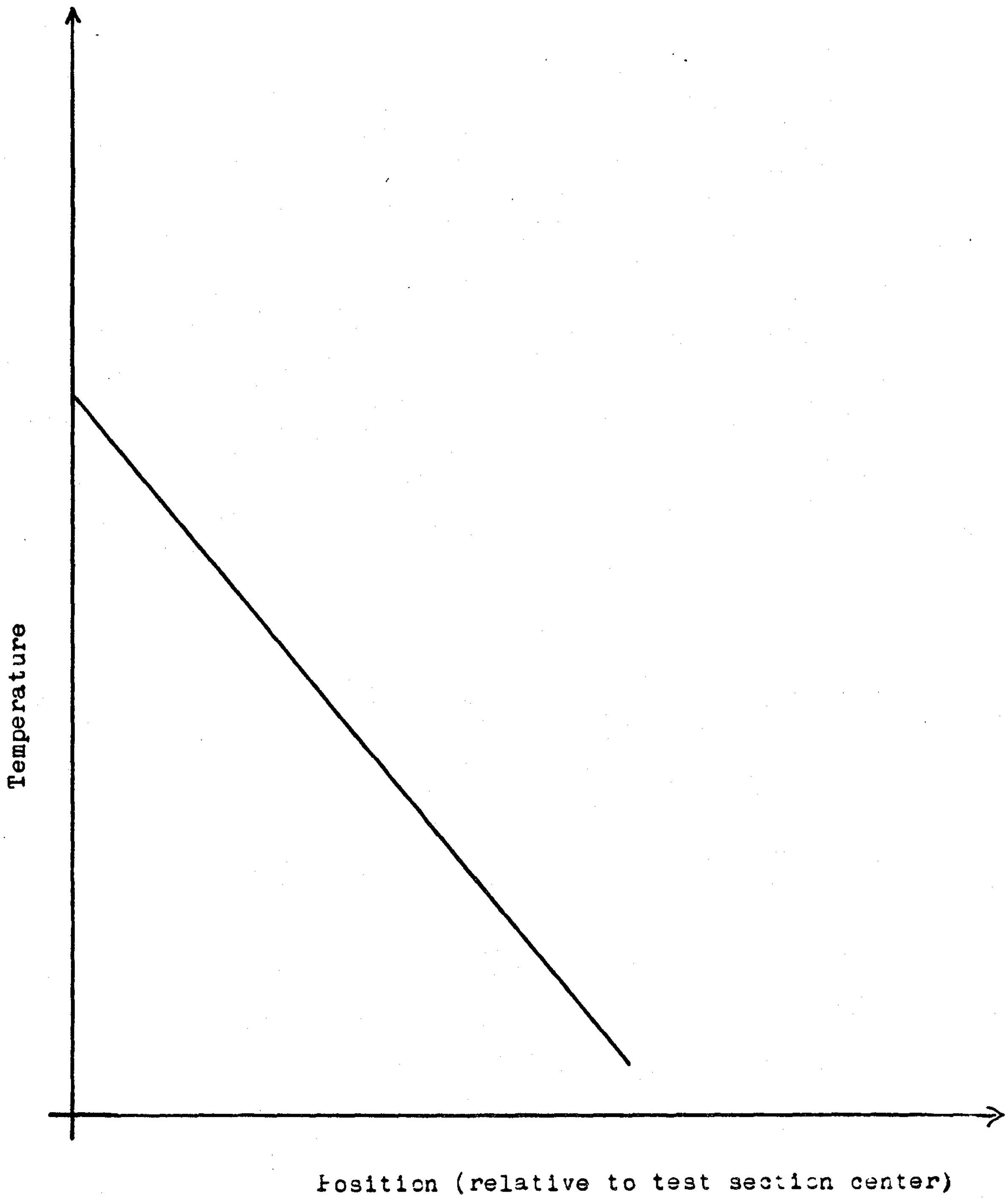


Figure 9 : Ideal Temp. Profile



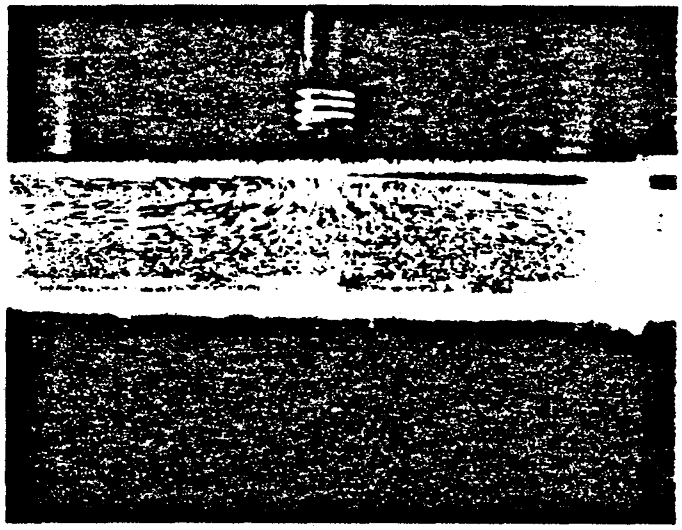
Heater 2 was chosen over heater 1 on the basis of temperature profiles. Heater 2 had a smaller coil diameter and therefore produced profiles with smaller positively sloped portions than did heater 1 (graph 1 #). Heater 2 also required less power to reach a given temperature (i.e., to become red hot, heater 1 required 35 watts while heater 2 required 17 watts).

The height at which the heater was positioned above the liquid surface was predetermined to be approximately 5.0mm (ref.1). This height was chosen to give an acceptable margin between the heater and the unknown free surface of the experimental fluid in zero-gravity conditions. Distances higher than 5.0mm were tested and did produce satisfactory convective flows, though the optimum convective flow pattern using heater 2 was produced at the lowest experimental height (5.0mm, at 17 watts). See fig.10. A good pattern was also produced with a heater height of 7.0mm (at 14 watts). The depth at which the convective flow reaches is not as great, but the flow pattern is very clear and symmetrical (fig 10).

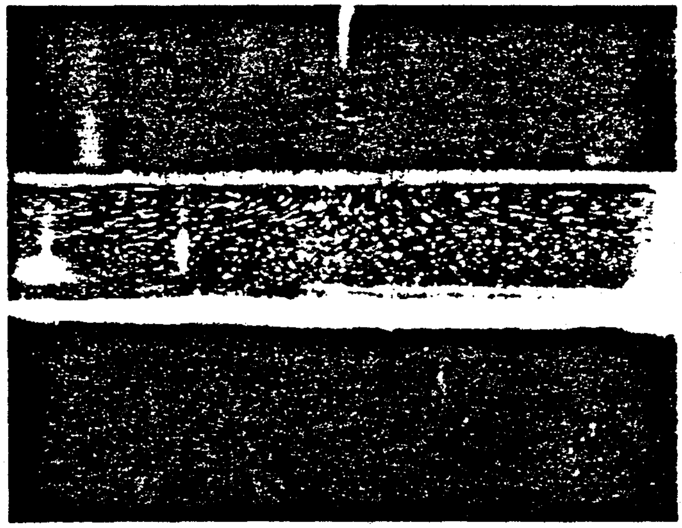
Heater heights of 2.0mm, 3.0mm, and 4.0mm were also tested (using heater 1) with the lowest height (2.0mm, at 14 watts) again producing the best convective flow pattern (fig.10). Less power is needed at this height but a safe height margin must be maintained so that the heater does not touch the liquid surface. Should the heater touch the liquid surface, the fluid will wet to the bottom heater coil loop, changing the shape of the free surface and causing localized, turbulent flow beneath the heater.

Power levels of 30, 60, and 100 watts to the heater (ref. 3) were previously specified. These power levels far excede the requirements of both heaters used in this experiment. Assuming a heater height of 5.0mm, power ranges of 20-30 watts (heater 1)

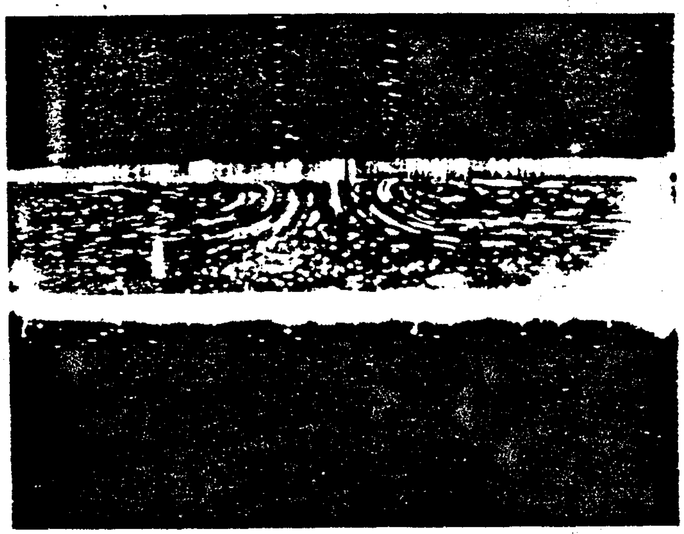
Figure 10 : Cptimum Flow Patterns



Heater 2
5.0mm
1 7 watts
(best)



Heater 2
7.0mm
14 watts
(good)

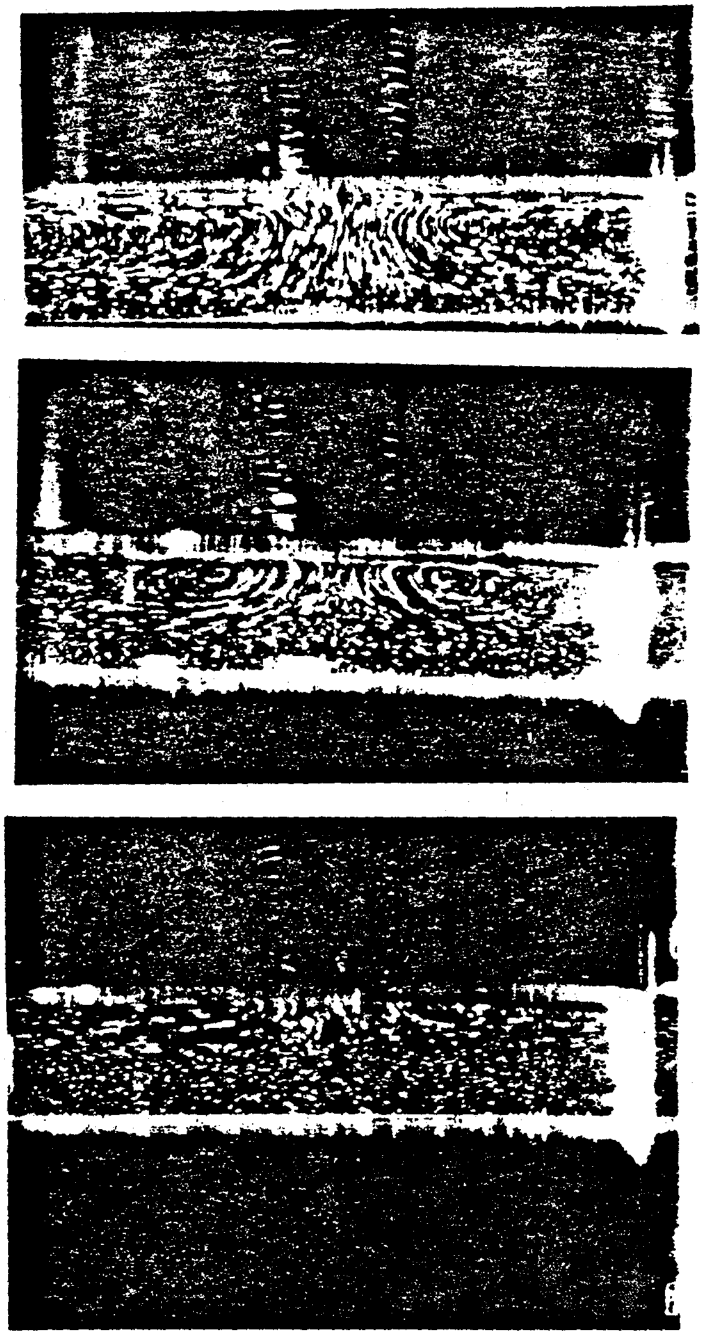


Heater 1
2.0mm
14 watts
(good)

and 14-18 watts (heater 2) were found to be the optimum for producing good convective flow. If the power level is steadily increased beyond these ranges, the convective flow patterns become progressively shallower and occur in a thin layer just below the liquid surface (fig.11). Another concern with increasing power levels is the radiant heating of the exposed test section side walls. If these walls are heated to a temperature exceeing that of the peripheral fluid of the test section, additional convective effects could be induced. Though plexiglass is an insulator, during experimentation the side walls were hot. No experiment was conducted to determine the effect, if any, of side wall heating on the convective flow pattern.

Temperature profiles were effected by three variables; namely, heater power, heater height, and which of the two heaters was used. This last variable listed was discussed earlier. The effect of increasing the heater power input merely increased the temperature values of the profile and did not significantly change the shape characteristics of the profile (graph 2#). The effects of increasing the heater height were decreased overall temperature values and peak temperature values occuring closer to the center of the test section (graph 3#). This second effect is desirable, since on temperature profiles it represents a diminishing positive temperature gradient portion and hence, a shrinking counter-productive flow force. Detailed data may be found in data table 2#.

Figure 11 : Increasing Power To Heater



6 watts

8 watts

32 watts

DISCUSSION AND RECOMMENDATIONS

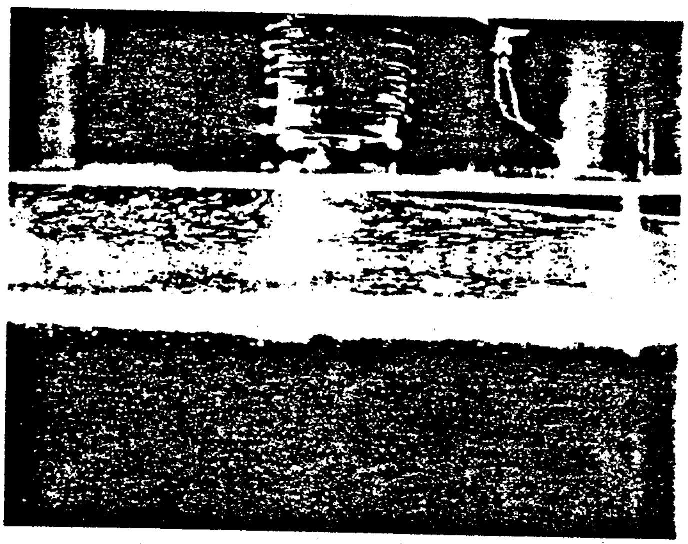
An important consideration when taking temperature data is the accuracy of the readings taken. Sources of error in temperature readings come from the following: depth positioning of the thermocouple junction, calibration of the millivolt potentiometer, and random temperature oscillations within the fluid itself (ref. 1). The last of these sources could cause the potentiometer zeroing meter to vary as much as ± 0.02mV ($\approx \pm 0.6^\circ$C). But since these oscillations are random in nature, they seldomly appeared effecting the overall data little. The depth at which the thermocouple junction was maintained at, could be kept constant within one junction diameter (0.3mm). This depth range corresponds to a potentiometer reading tolerance of ± 0.01mV ($\pm 0.3^\circ$C). The error introduced by the potentiometer is the least of the three at $\pm 0.1^\circ$C (ref. 1). The final temperature data presented is rounded to three significant digits, with accuracy claimed at $\pm 0.3^\circ$C. In this experiment, true temperature readings are not of extreme importance, but rather temperature gradients are of interest. Since temperature readings are compared to one another, experimental error tends to be minimized.

An interesting effect was noticed when heating the silicone fluid. The illuminated cross section of fluid would develop a wedge shaped patch of darkness, originating at the surface under the heater and extending toward the test section wall (fig. 12). The effect can be explained by the temperature gradient within the fluid causing the laser light to bend (ref. 4). Thus, all the particles within this dark zone can not be detected, visually or photographically. The dark zone increases in size as the power is increased, creating another reason to minimize the

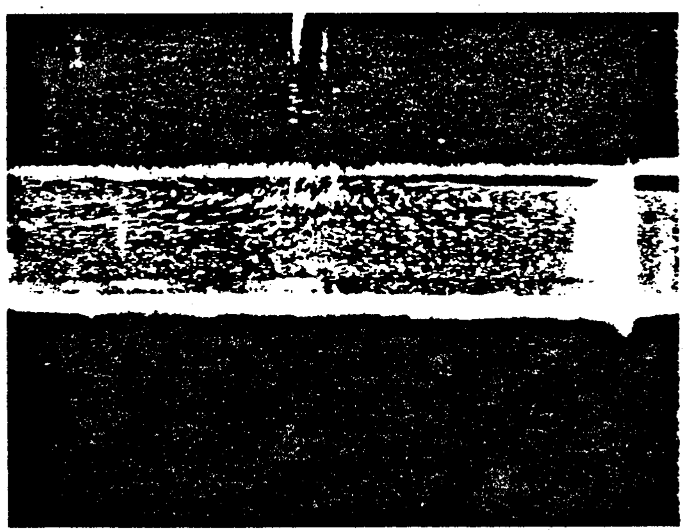
Figure 12 : Wedge Effect

To Laser

←



Heater 1
at 36 watts
Height-6mm



Heater 2
at 14 watts
Height-6mm

heater power input.

The following is a list of areas where additional experimentation is recommended : optical system, particle variety, test environments, and temperature measurement. The optical system should have a laser plane that is wide enough only to illuminate the liquid cross section as opposed to a continuosly diverging plane of light. A glare-free and darkness-free side view of the illuminated cross section should be developed for photographic study purposes. More different types of particles should be tried. This experiment would also benefit if it were conducted in a clean-room facility to avoid possible contamination of the fluid or test section. Lastly, a more precise and faster method should be used to record temperature data. An infrared radiometric microscope or a similar instrument could possibly be used as a nonintrusive way of measuring surface temperature. These recommendations will hopefully help aid future experimental research and ultimately, help to further the understanding of surface tension driven convection flow.

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1) Kamotani, Dr. J., Department of Mechanical and Aerospace Engineering, Case Western Reserve University, Cleveland, Ohio.

2) Manja, Sudin, "Optimization of Particle Size and Concentration, and Fluid Type for Flow Visualization", Department of Mechanical and Aerospace Engineering, Case Western Reserve University, Cleveland,Ohio, August 1983.

3) Concept Development (Two Space Shuttle Fluid Physics Experiments), contract NAS 3-23774, Briefing NASA/LEWIS Research Center, Cleveland, Ohio, January 27, 1983.

4) Lowry, Samuel, "An Experimental Study of Heat Induced Surface Tension Driven Flow", Department of Mechanical and Aerospace Engineering, Case Western Reserve University, Clevland, Ohio.

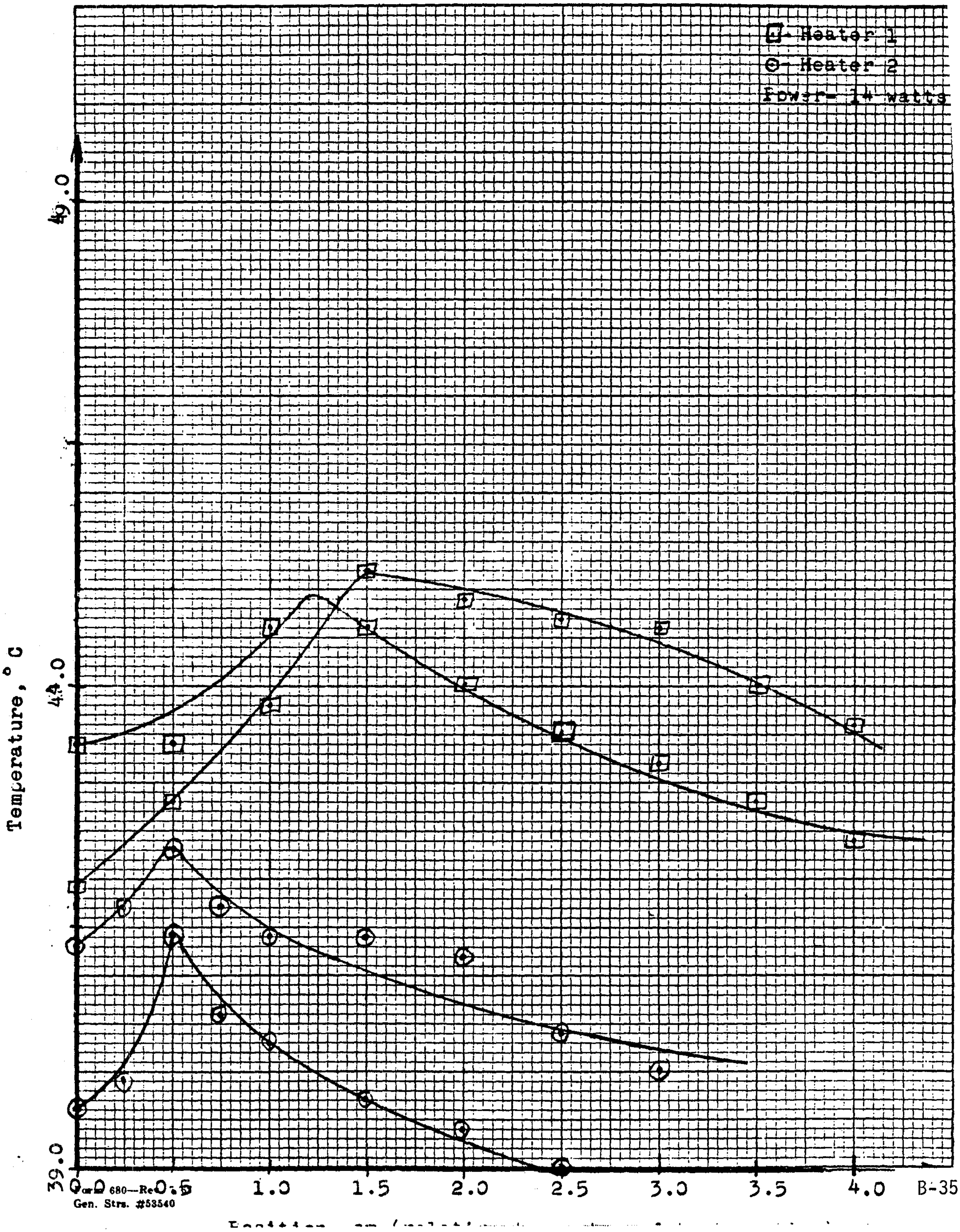
DATA TABLE 1#

Fluid Type	Vol. (ml)	Particle Type	Mass (mg)	Comments: s-sparse l-light m-medium h-high v-visual p-photographic c-concentration
10cs Silicone Oil	99.1	alpha-Alumina (1μm)	.05	v s c p s c
	99.2		.10	v s c p l c
	99.3		.15	v l c p l c
	99.4		.20	v l c p l c
	99.5		.25	v l c p l c
	99.6		.30	v l c p m c
	99.7		.35	v l c p m c
	99.8		.40	v l c
	100.0		.50	v l c
	100.2		.60	v m c p m c *-optimum
	100.4		.70	v m c
	100.6		.80	v m c p m c
20cs Silicone Oil	99.2	alpha-Alumina (1μm)	.10	v l c p l c
	99.4		.20	-
	99.5		.25	v l c p l c
	99.6		.30	v m c p m c
	99.7		.35	-
	99.8		.40	v m c p m c
	99.9		.45	- *-optimum
	100.0		.50	v m c p m c
	100.2		.60	v m c
	100.4		.70	v h c

LATA TABLE 2#

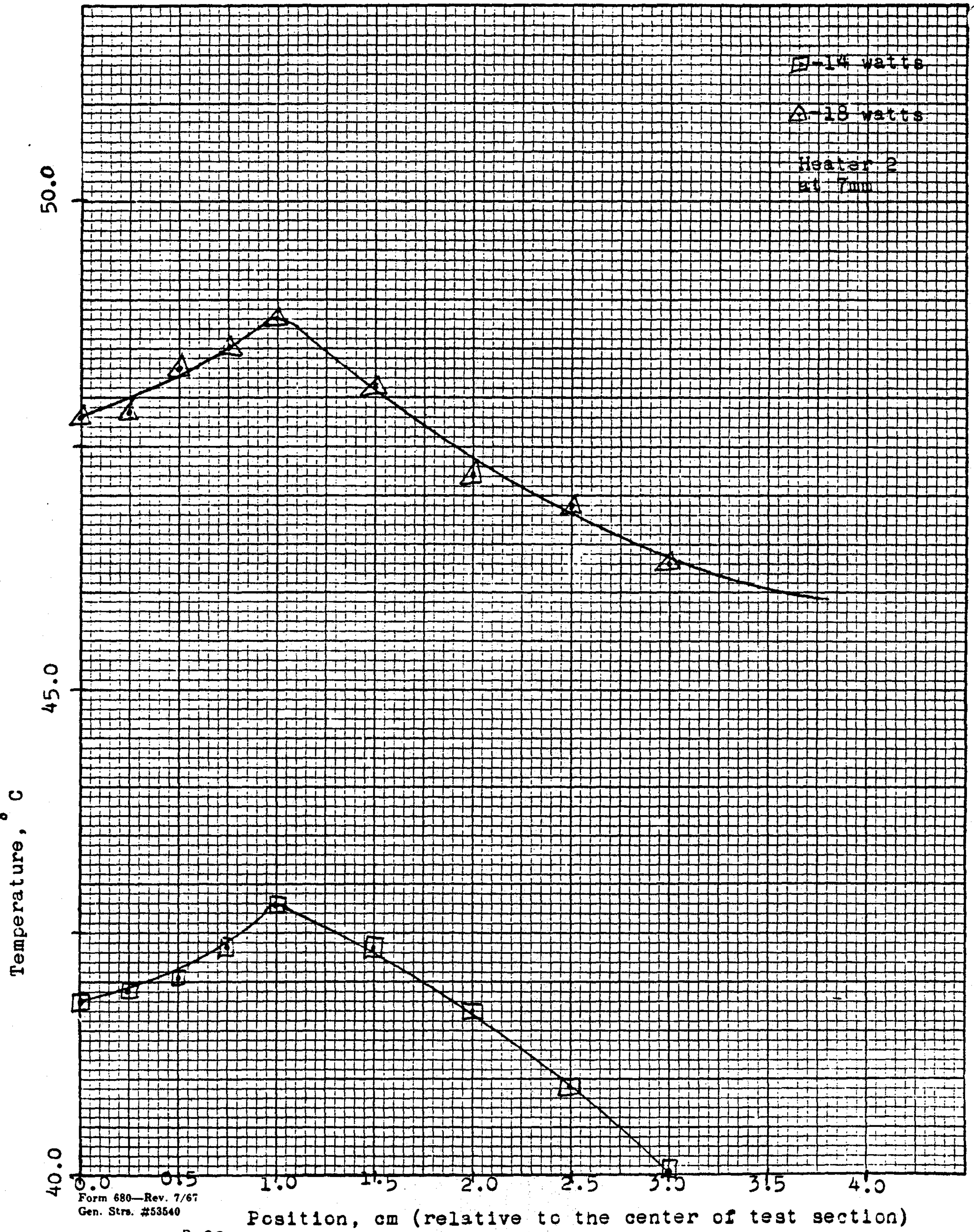
Heater 1				Temperature °C, At Position (cm) Relative To Center									
Height (mm)	Volts	Amps	Power (watts)	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	(cm)
2.0	3.0	2.2	6.6	33.5	33.7	34.4	34.3	34.0	33.7	33.6	33.7	33.4	
2.0	5.0	2.8	14.0	41.9	42.8	43.8	45.2	44.9	44.7	44 6	44.0	43.6	
2.0	6.0	3.0	18.0	49.9	50.2	52.0	52.9	52.0	52.0	51.8	51.5	50.2	
2.0	8.0	3.7	29.6	68.2	70.5	74.5	75.8	76.6	77.7	75.7	75.8	71.2	
3.0	5.0	2.8	14.0	43.4	43.4	44.6	44.6	44.0	43.5	43.2	42.8	42.4	
4.0	6.0	3.0	18.0	50.6	51.1	52.5	52.0	51.1	50.5	49.8	48.9	48.3	
4.0	8.0	3.7	29.6	68.6	69.4	72.5	73.4	73.3	72.7	72.2	70.6	70.6	
5.0	8.0	3.7	29.6	66.2	68.7	71.8	71.5	70.9	70.6	70.1	69.3	68.9	
6.0	9.0	4.0	36.0	78.8	79.5	80.8	81.5	81.4	80.9	80.4	79.3	78.9	
Heater 2				0.00	0.25	0.50	0.75	1.00	1.50	2.00	2.50	3.00	(cm)
5.0	3.0	4.6	13.8	39.6	39.9	41.4	40.6	40.3	39.7	39.4	38.8	38.4	
5.0	3.4	5.0	17.0	45.9	46.3	47.1	46.9	46.8	46.0	45.1	44.0	43.2	
6.0	3.0	4.6	13.8	41.5	42.3	42.6	42.3	41.9	41.3	40.6	40.0	39.4	
6.0	3.5	5.2	18.2	47.3	47.9	48.1	48.9	49.0	48.9	48.3	47.5	47.0	
7.0	3.0	4.6	13.8	41.3	41.8	42.3	41.8	41.4	41.4	41.2	40.4	40.0	
7.0	3.5	5.2	18.2	47.8	47.8	48.3	48.5	48.8	48.1	47.2	46.9	46.3	

GRAPH 1#



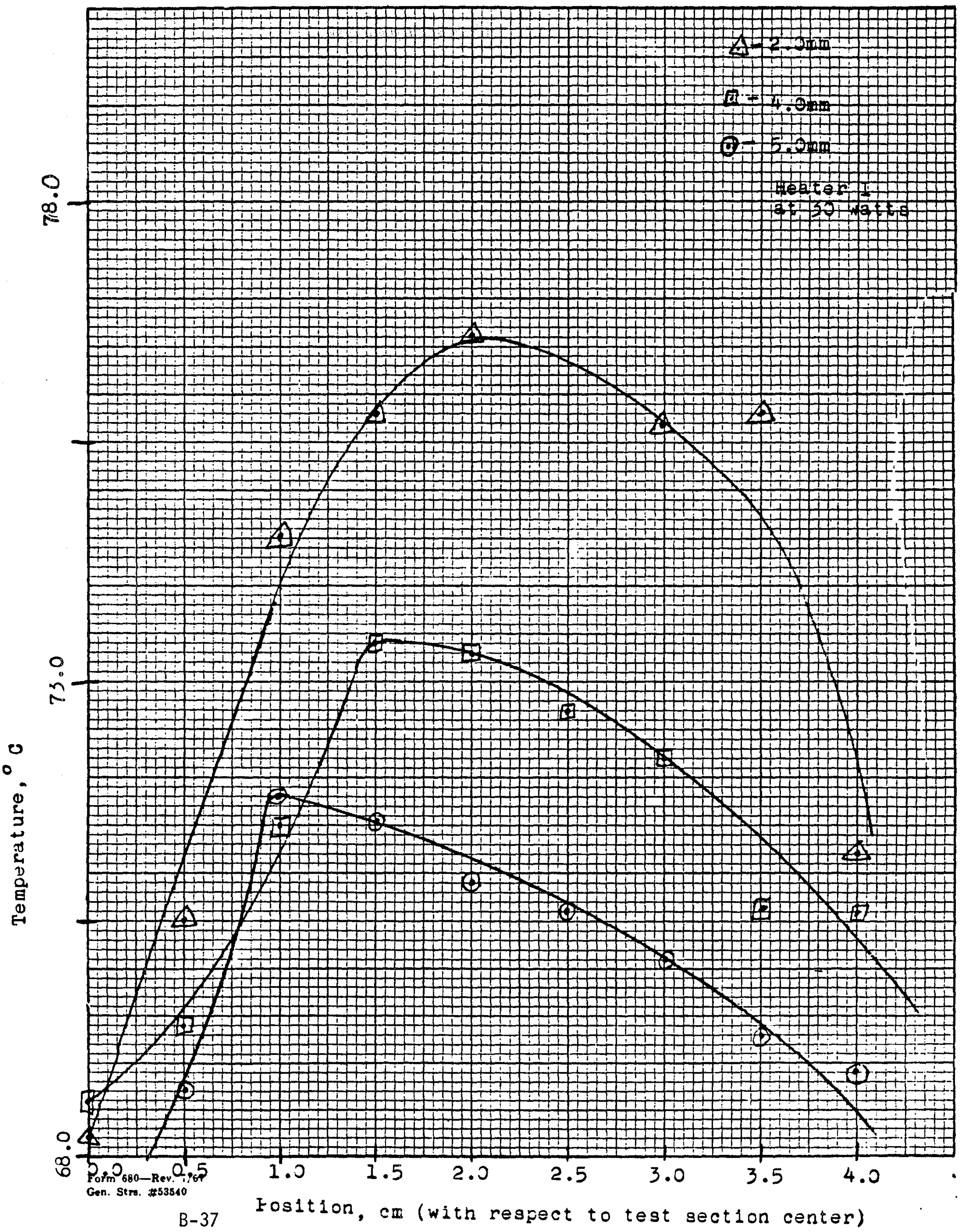
Form 680—Rev.
Gen. Strs. #53540

Graph 2# : Increasing Heater Power and Temp. Profile



Form 680—Rev. 7/67
Gen. Strs. #53540

Graph 3# : Increasing Heater Height and Temp. Profile



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A P P E N D I X   C

Cameras and Films

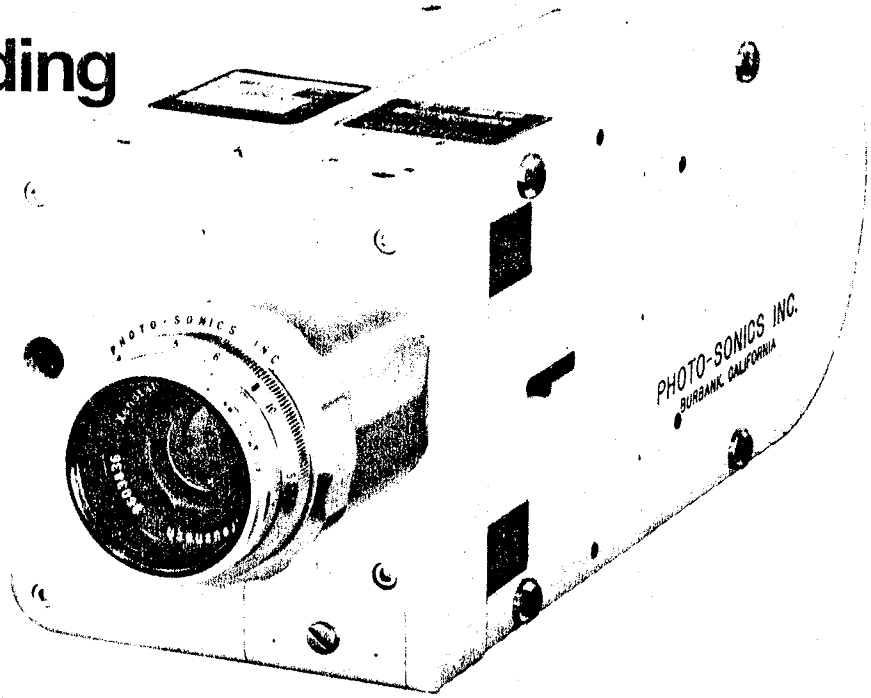
This appendix contains literature obtained on the camera chosen (Photosonics 35 mm-4ML) and films that will potentially be used in the experiment. The sensitivity curves are given where available.

INSTRUMENTATION MARKETING CORP.
820 S. Mariposa St., Burbank, CA 91506/Phone 213 849-6251, Telex 67-3205

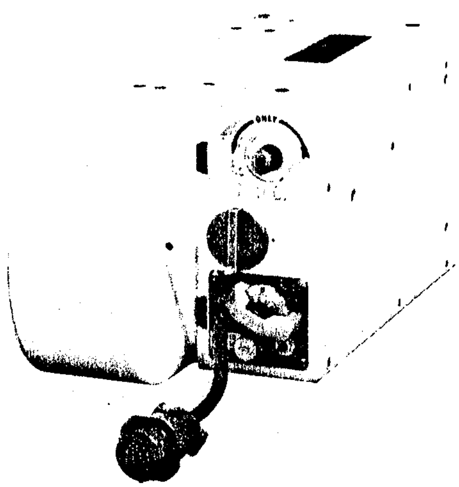
Spec/Data Sheet

May 1983

Photo-Sonics magazine loading camera Series 2000 35mm-4ML



High-speed intermittent pin-registered



The most versatile high-speed 35mm motion picture camera available today . . . capable of normal speed, and up to 200 fps . . . featuring interchangeable magazines of 200′, 400′ and 1000′, plus the new state-of-the-art synchronous phase lock and remote speed control options!

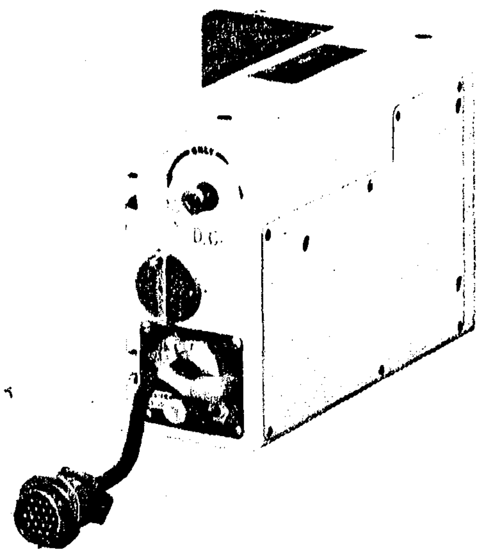
This unique, rugged data recording camera is exceptionally clean in mechanical and electrical design for high reliability to meet exacting requirements for medium high-speed motion picture jobs today.

Unique features —

- Variable shutter can be externally adjusted quickly and easily with no tools; no re-timing of camera required.
- Neon or LED timing lights may be easily replaced from outside the camera, without disturbing the film load.
- Boresight provides positive and direct straight-through viewing. Because of quick-change magazine capability, boresighting can be accomplished in minimum time.
- If usage dictates different film capacities, different film magazines are available rather than purchasing an entire new camera, resulting in considerable cost savings; 200,′ 400′ or 1000′ magazines interchange with no adjustment to camera or magazine.
- Each magazine has a spring-loaded viewing port for viewing film loops.
- Magazines are near-automatic threading with no climbing loop.
- Because the magazine can only be properly threaded one way, timing mark offset is always 7½ frames.
- Film magazines can be interchanged in less than 5 seconds and camera/magazine drive interface is automatically aligned.
- All film magazines thread identically and film is always positively locked by either the two register pins or the four pulldown pins.
- Phase lock synchronization plug-in module option.
- Remote speed control option.
- Plug-in AC or DC power amplifier has unique reverse polarity protection including audible alarm to warn operator.

Camera body includes —

a 28V DC motor (115V AC 50/400 Hz motor available at no additional cost), shutter, top, bottom and side mounting provisions, continuously variable speeds from 10 to 200 fps, runout switch, 115V AC thermostatically controlled heaters for −65°F, special Photo-Sonics interrupted thread bayonet lens mount with dust cover, camera dust cover, dual neon timing lights (LEDs optional at no additional cost), manual advance knob, press-to-operate switch, connector, oil and instruction manual. Out-of-film indicator standard.



Camera electronics —

The modular electronics are solid state and the motor speed control is pulse width modulated.

This type of system is inherently less sensitive to voltage and temperature variations, providing greater accuracy and stability than found in comparable analog systems. A unique protection circuit prevents damage to the electronics in the event of a mechanical failure.

An acceleration control circuit provides smooth starting. A remote start capability requires only 25 ma from a 28-volt source, eliminating the need for switching main camera power. A press-to-operate switch is located at the back of the camera; this allows check-out of the camera by the operator without trigger circuits being actuated.

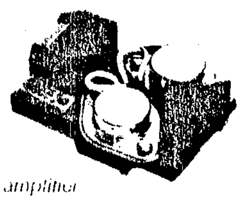
The servo control is on one plug-in printed circuit board held in place by captive thumb screws. This board is *completely* interchangeable between cameras with no re-calibration adjustments necessary.

The complete electronics, including harness, can be removed from the camera without the use of a soldering iron.

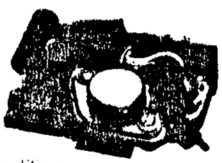
All cameras are wired to accept the synchronization phase lock module and remote speed selector module.

Outstanding features include—

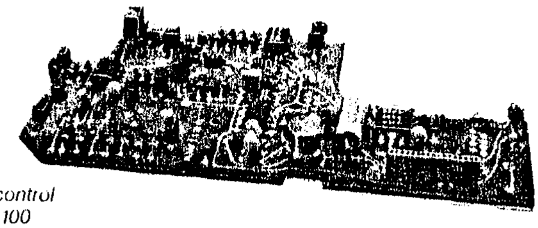
- AC/DC convertability.
- Plug-in servo control board.
- Plug-in option for phase lock and synchronization to external pulse.
- Plug-in shutter correlation pulse electronics.
- Interchangeable PC board, power amplifier and phase lock electronics between the 35-4ML and Photo-Sonics 16-1PL cameras. Minor adjustments required.
- The old style 35-4M camera may be used as a master to drive the new 35-4ML cameras provided cameras are modified with a new shutter correlation pulse.
- Out-of-film indicator. Contact closure to 28V DC return when magazine is out of film.
- Plug-in AC or DC amplifier. DC power amplifier has unique reverse polarity protection including audible alarm to warn operator.



DC amplifier
P/N 61-9573-100

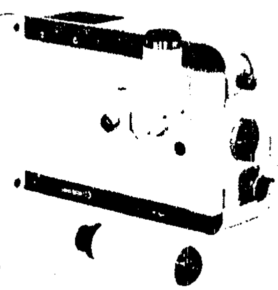


AC amplifier
P/N 61-9511



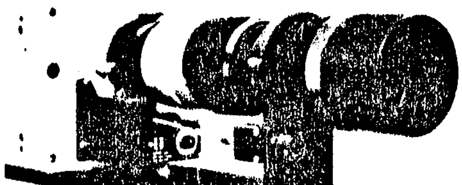
Servo motor control
P/N 61-9640-100

Boresight tool —



Two adapters are provided for maximum flexibility: one right angle, and one straight, for side, top and back viewing allowing alignment and focusing from almost any position. The ground glass is spring loaded, assuring contact of the glass to the aperture plate or focal plane. Installation of the boresight is the same as the magazines . . fast and no problem.

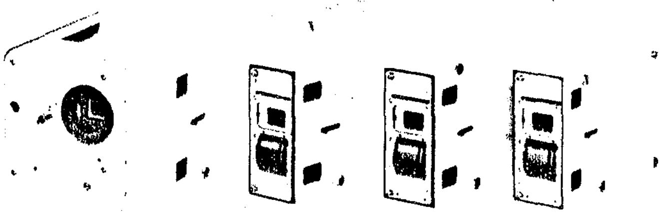
Automatic exposure control —



The 35-4ML accepts the field-proven Apex-B "bolt-on" automatic exposure control system manufactured by Photomatrix. Many accessories are available to meet most requirements. A separate data sheet covers the AEC.

Magazines —

The real uniqueness of the 35-4ML lies in the magazine loading concept. The movement is built-in and provides positive film control through the use of dual registration pins and/or four pulldown pins at all times. The film may be threaded in less than one minute and the magazine installed on the camera in less than 5 seconds. There are no film guides or shoes, sprocket guards or levers to release or move in order to load the film. Even the climbing loop is gone. It is the closest thing to automatic threading — yet, still gives the operator complete control at all times. All magazines are gear driven and do not require any take-up motors. A sliding door is provided in the magazine door to allow viewing of the film transport and film without disturbing the camera set-up.



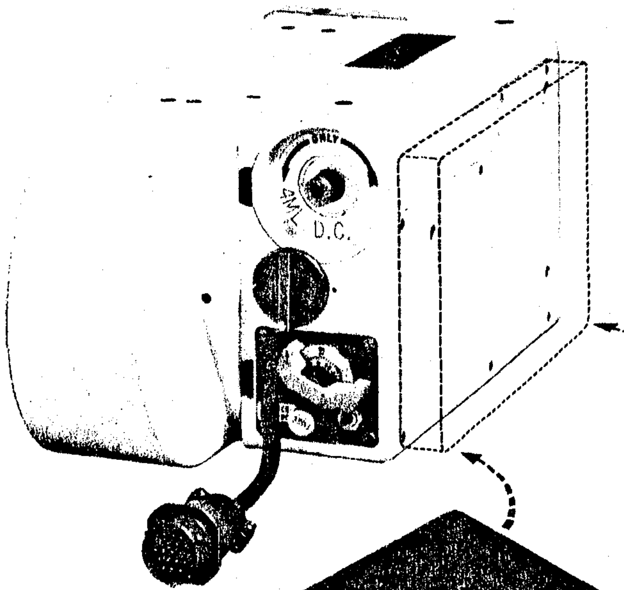
35-4ML with 1000′ coaxial magazine | *400′ vertical magazine* | *400′ horizontal magazine* | *200′ magazine*

200′ — darkroom loading, daylight threading; weight w/film, 7 lbs.

400′ — darkroom loading, daylight threading; weight w/film, 11 lbs.

1000′ — darkroom loading of one of two interchangeable film spools, daylight threading; weight w/film, 20 lbs.

Phase lock synchronization electronics...

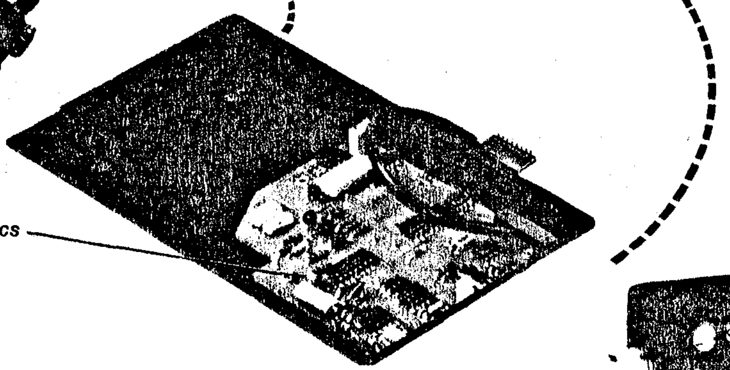


This module can be added to the side of the camera without any factory modification. It increases the overall camera width approximately ¾″. The camera must be equipped with a shutter correlation pulse module which can also be easily installed in the field.

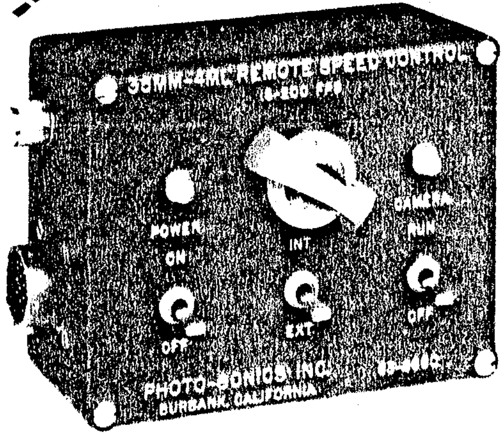
The module provides several options in controlling one or more cameras. It can be used for phasing the shutter from an external pulse to an event which simultaneously makes the camera run synchronous to the input pulse.

The shutter correlation pulse in a camera can be used as an input pulse to other 35-4ML cameras equipped with this module which will make them run synchronous to the master camera.

A built-in dual sensor in the camera simultaneously permits synchronization and out-of-phase modes between cameras. For example, two cameras running at the same speed can also be operated 180° out-of-phase with each other. When three cameras with 140° shutters are phased 120° from each other . . . an event can be recorded continuously, 100% of the time.



Phase lock electronics



Remote speed control —

An optional remote speed control is available, using the same module as the phase lock electronics. This provides the additional capability of changing the frame rate, from a remote location, to any speed between 15 fps and 200 fps, up to 500′ away given proper interface.

Standard specifications, 35-4ML

Frame rate: 10 to 200 fps by transistorized variable speed control. Accuracy ± 1% or ± 1 frame, whichever is greater.

Aperture size: 0.745" × 0.995"

Film specification:

Standard—
USA PH22.36 (KS .1870" pitch)

Optional—
USA PH22.93 (BH .1866" pitch)
USA PH22.34 (BH .1870" pitch)
USA PH22.139 (KS .1866" pitch)

Camera accepts both .004 and .006 inch film.

Film capacity: 200 ft. magazine; 400 ft. magazine (horizontal and vertical); 1000 ft. magazine (coaxial).

Film transport: Intermittent, two registration pins and four pull-down pins with film held captive in aperture gate at all times.

Shutter: Variable rotary disc with openings of 9, 18, 36, 72, and 144 degrees.

Timing lights: Two, one each side of film outside picture area; uses NE2J lamps. LEDs may be substituted at time of purchase at no additional cost.

Motor: 115V AC, 50/400 Hz, 4 amps max. at 200 fps; 28V DC, 12 amps max. motor available upon request at no additional cost at time of order.

Weight: 9¾ lbs. (camera body only)

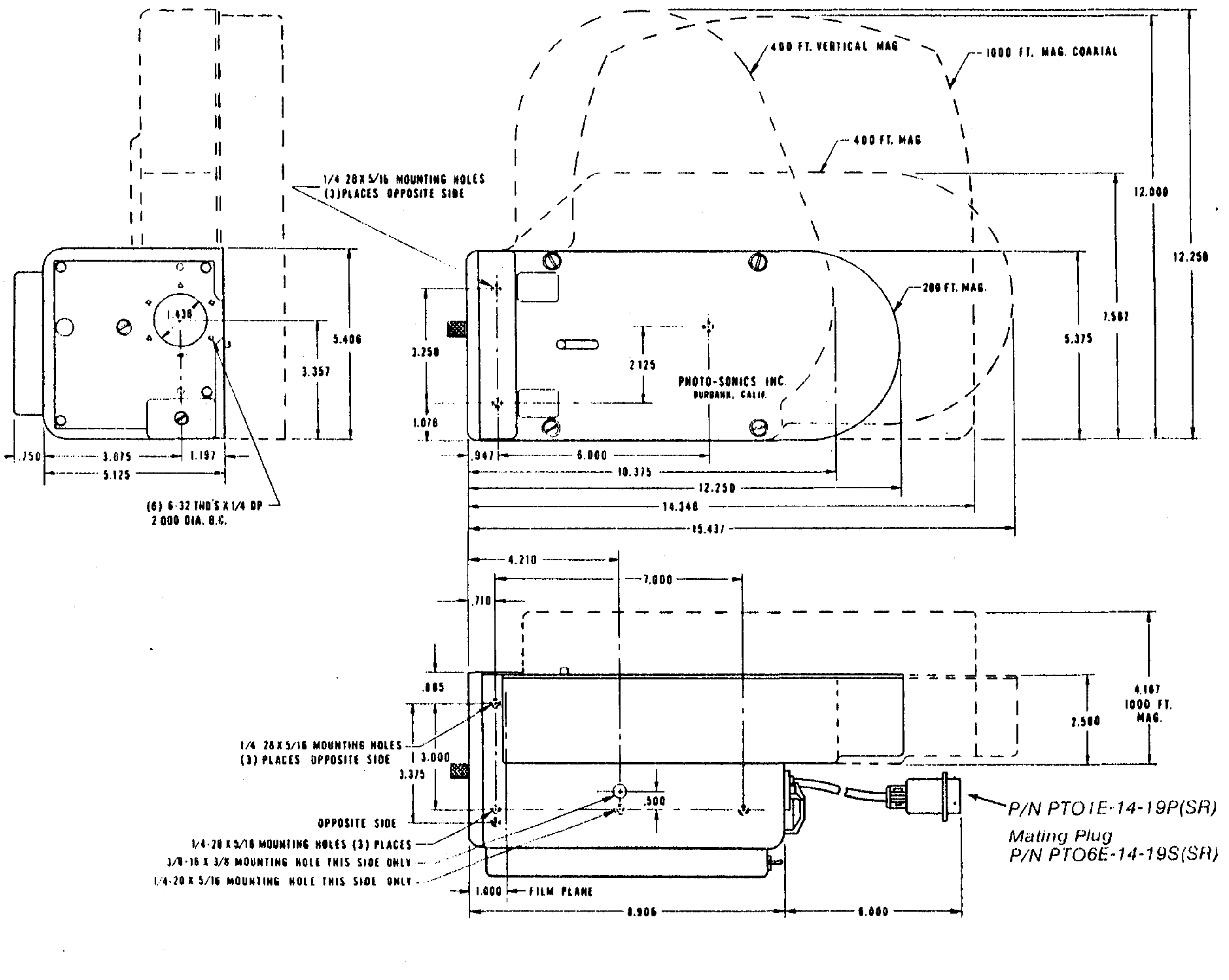
Mounting: Top, bottom, and right side of camera.

Lens mount: Special bayonet Photo-Sonics interrupted thread. (Nikkor mount optional at extra cost)

Heater: 115V AC or DC, 300 watts, thermostatically controlled.

Specifications subject to change without notice.

Outline drawing —



Shaded area indicates phase lock synchronization

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16mm cameras—
Rotary prism

Photo-Sonics Model 16-1B: High "G", extreme temperature and vibration; short run stop/start, full run of interchangeable magazines of 100′ and 200′ at speeds from 10 to 1000 fps.

Model 16-1BAC is 115V AC version of the 16-1B, also accepts 400′ magazine, speeds of 200, 400, 600, 800 and 1000 fps, NOT for high "G" use.

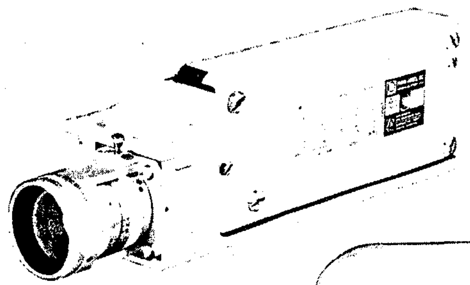
NAC Model E-10: 400′ capacity, 100 to 10,000 fps, stop/start up to 3000 fps, optional oscillograph recording simultaneous with picture, mechanical event synchronizer, electronic speed, control, direct reflex viewing while running.

SPECIAL PRODUCTION MODELS

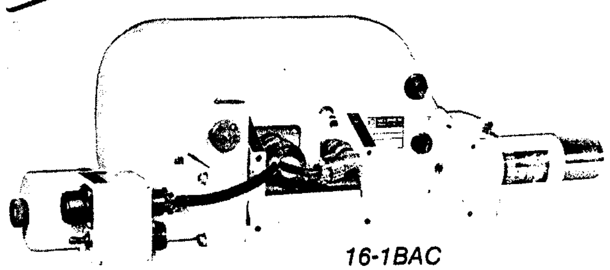
Photo-Sonics Model 16-1C: High "G", extreme temperature and vibration, 400′ magazine, speeds to 4000 fps.

Photo-Sonics Model 16-1E: 100 "G", very small, 25′ daylight spools, 200 to 600 fps.

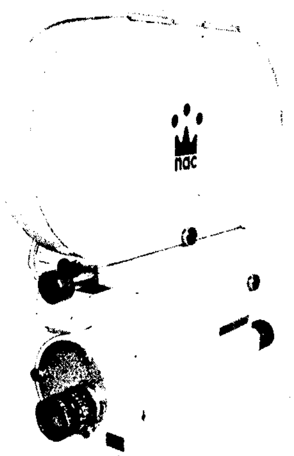
Photo-Sonics Model 16-1F: Watertight, operates under 150 "G" loads, 100′ daylight load spools, 200 to 1000 fps.



16-1B



16-1BAC



E-10

16mm cameras—
Intermittent pin-registered

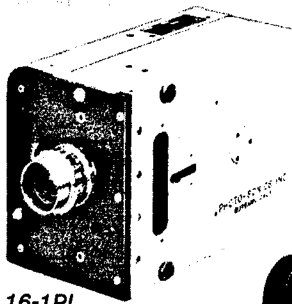
Photo-Sonics Model 16-1PL: 10 to 500 fps, AC/DC convertible, interchangeable 200′, 400′ and 1200′ magazines. Sync phase lock, continuous reflex optics, pulse kit, built-in timing light generator, wired for automatic exposure control.

Photo-Sonics Actionmaster/500: Hand-held version of the 16-1PL features continuous reflex viewing to 500 fps, dual speed controls, 24 fps crystal option. Ideal for instrumentation photography as well as documentary/super slow motion.

Photo-Sonics Model 16-1VN: Smaller than most Super-8s and versatile! Up to 12 pps and cine to 100 fps, or cine only from 24 to 200 fps, interchangeable 65′, 100′ and 200′ magazines, and provisions for "add-on" automatic exposure control.

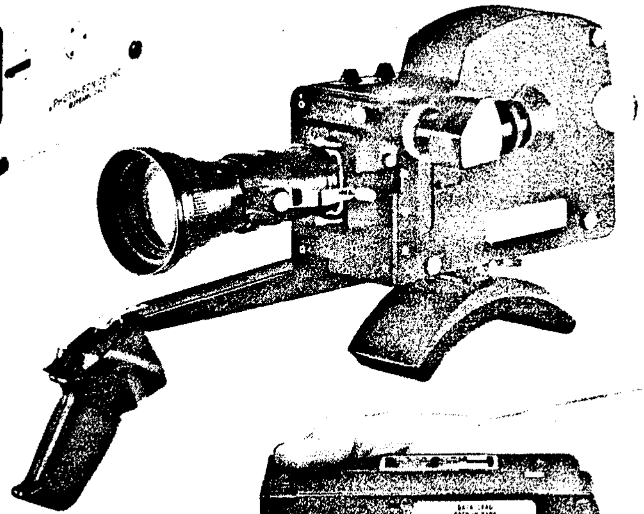
SPECIAL PRODUCTION MODEL

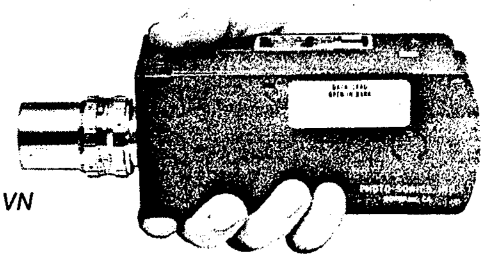
Photo-Sonics Model 16-1W: Fastest intermittent 16mm camera in the world! 24 to 1000 fps, interchangeable 200′ and 400′ daylight load magazines.



16-1PL

Actionmaster/500





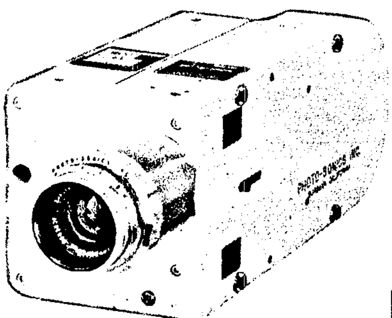
16-1VN

35mm cameras—
Intermittent pin-registered

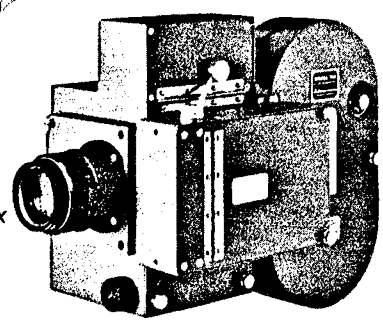
Photo-Sonics 35-4ML: 10 to 200 fps, interchangeable 200′, 400′ and 1000′ magazines, plug-in electronics, AC/DC convertible, accepts "add-on" automatic exposure control. Synchronous phase lock and/or remote speed control options.

35-4MLX: X-ray version of 35-4ML for cineradiological applications; 16 to 200 fps in any 7 discreet speeds pushbutton-selectable, remote control indicators; camera triggers X-ray. Available in single-plane or bi-plane systems.

Automax Cine/Pulse Series G: Pulse to 10 pps, cine to 16 fps, variety of combinations of AC/DC, single/double frame advance and data box; 100′, 200′ and 400′ Mitchell mount magazines, solid state electronics. Over 20 models to choose from.



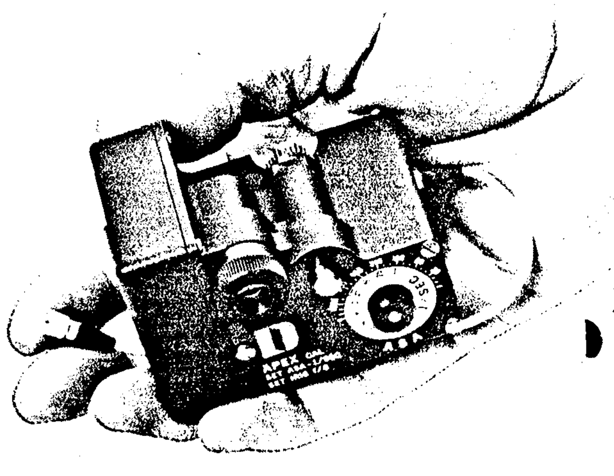
35-4ML



Automax

Automatic exposure controls—

Photomatrix Apex-B: For most 16mm and 35mm cameras, "bolt-on", rugged, accurate, covers a light range from 5 to 20,480 foot-lamberts, ASA 25 to 1600 in 1/3 f-stop increments, accommodates shutter speeds from 1/12 to 1/12,800 sec. in 1/3 f-stop increments, response time less than 2 sec. through full 6 f-stop range, encapsulated integrated circuitry.

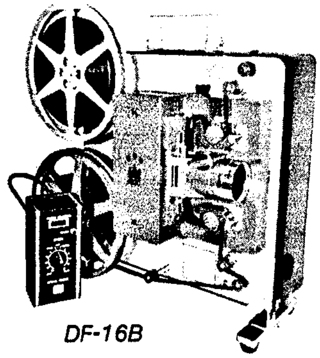


Projectors and film readers—

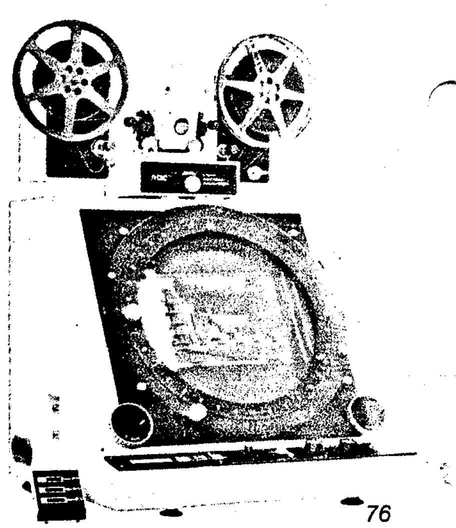
NAC analysis projector Model DF-16B: 16mm, ***flicker-free at all speeds,*** 0 to 24 fps continuously variable forward/reverse, single frame forward/reverse, instantaneous stop for frame-hold at any speed, constant illumination at all speeds and stop-motion with no film damage, remote control box with illuminated electronic frame counter.

NAC film reader systems Models 160B, 350B, 700B: 16mm and 35mm are ***flicker-free at any speed*** forward/reverse; interchangeable 16mm, 35mm and 70mm projection heads rotate 360°, X-Y motorized joystick, multiple frame advance and lamp intensity control. Available in metric or English readout. Angle measuring screen and 35mm camera attachment option. Optional RS-232 output.

NAC data analyzer Model 76: Combines the film motion analyzer with a digitizing tablet, mini-computer or micro-processor and teletype or HP-85 terminal for use in cine angiography, biomechancis, ambulation and automobile safety film analysis. Programs include line length, angles, volume scale factors, stick figures and center of mass calculations.



DF-16B



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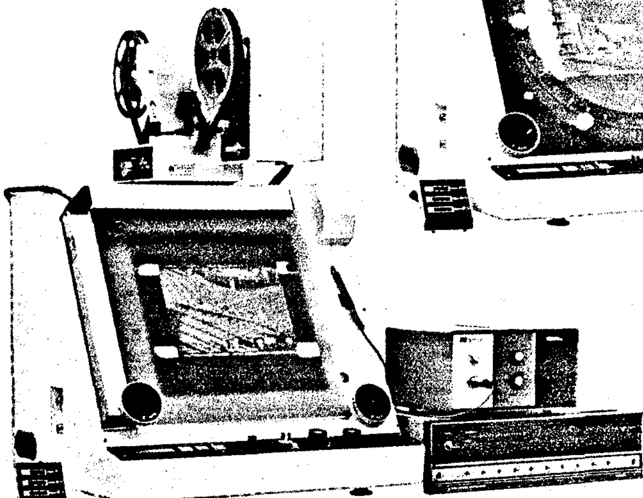


160B, 350B, 700B

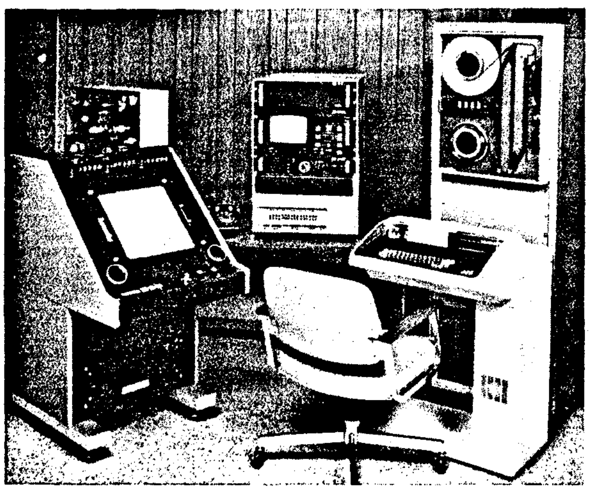
Automatic film reading digital analysis systems—

These 16mm, 35mm and 70mm systems lend themselves to automatic film reading jobs where specific types of information are recorded on film such as dot matrices, alpha-numerics or vernier dials plus cooperative shapes which might include a dot, cross or quadradic target.

These are often found in high-speed instrumentation films used in range tracking applications, car crash studies, biomechanics research, the medical field, plus a host of other categories.

The standard NAC/PDS Model 78: consists of NAC rear projection case and projection head, PDS electronic control console with scan converter and Data General Nova series mini-computer, teletype, magnetic tape recorder and software. Variations might include video display terminal and disc.

The standard Photo-Sonics/PDS Model 80: The Model 80 consists of a front projection film reader console with digitizer table, control panel, cursor, floating keyboard and display, foot switch, x, y, frame LED display, film transport, light source and optics, plus PDS Digitizing camera and relay optics. The electronic control console with control unit, scan converter and Nova 4 digital processor, magnetic tape recorder. CRT remote display terminal, disc and software make up the remainder of the complete system.



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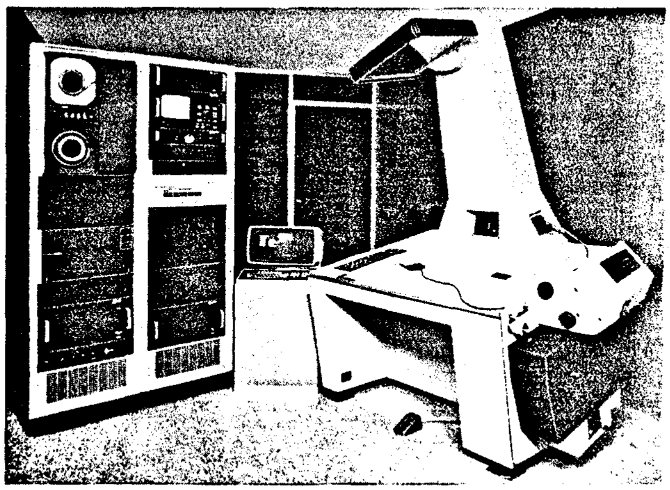


Timing systems—

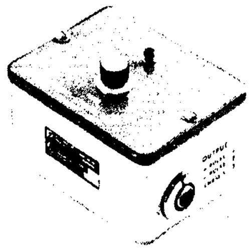
Photo-Sonics timing light generator Model TLG: Small, solid state and accurate, drives more than 10 neon lamps, provides pulses at 10, 100 and 1000 per second. 28V DC or 115V AC.

Model RTLG is the ruggedized high "G" version of the TLG, 28V DC only.

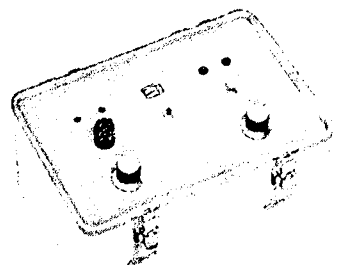
Photo-Sonics timing pulse generator Model CTPG/LED: Provides coded output to facilitate reading at 100 and 1000 pulses per second, plus circuit for Event marks. Made especially to drive LEDs. 115V AC, 28V DC or 12V DC internal NiCad battery with built-in recharger. IRIG option available to drive LEDs.

Photo-Sonics multiple camera driver Model MCD/LED: Accepts Time and Event data from the Model CTPG or other LED pulse generator and drives the data to as many as four cameras. These units may be ganged. 115V AC, 28V DC or 12V DC internal NiCad battery with built-in recharger.

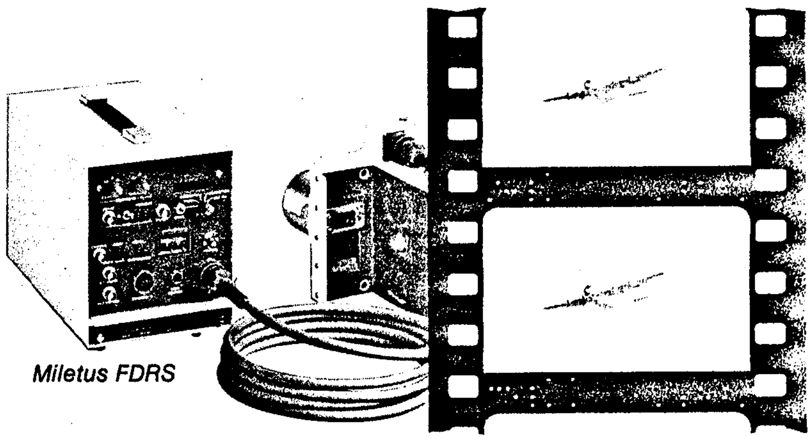
Miletus FDRS (film data recording system): Designed around CMOS technology for low power and noise immunity, adaptable to most 16mm, 35mm and 70mm cameras, on-camera or remote—ground or airborne, contact-printing super miniature 7-segment format or BCD on every film frame up to 10,000 fps. Internal rechargeable battery provides 24 hours operation on a single charge, plus built-in translator to accept IRIG or operate on internal crystal clock.



TLG



CTPG/LED



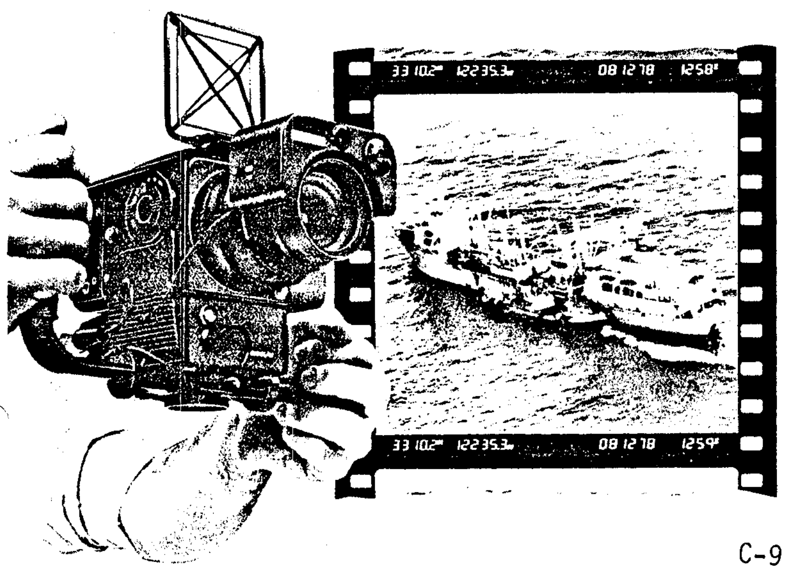
Miletus FDRS

Special equipment and accessories—

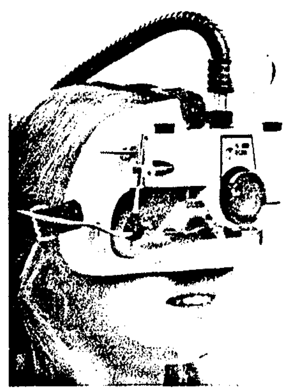
Airborne surveillance documentation system: A unique hand-held photographic data recording system for airborne, land and maritime surveillance that simultaneously documents latitude, longitude, date, GMT, or additional data on every frame of film.

The camera system is comprised of a selection of standard Hasselblad components. Customer's existing photographic equipment may also be utilized.

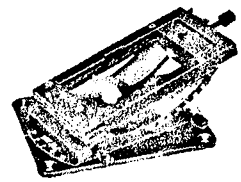
The controller, designed around CMOS technology, is in a quarter-dwarf ATR chassis and accepts ARINC 571, 575, etc., decodes it, and direct-prints data on the film by a 7-segment recording head.



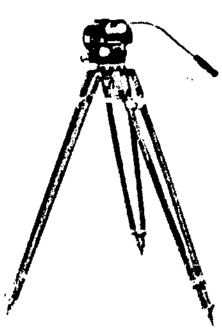
NAC eye movement recorder Model 4: Continuously records a subject's discreet visual point of interest and simultaneously superimposes a field image on each frame of film taken through a main objective lens, and relayed via fibre optics to TV or 16mm camera.



Camera mounts: With quick connect/disconnect dovetail mounting plates.



O'Conner tripods and fluid heads: excellent quality and performance.



Tracking finders: Superimposed reticle is illuminated by ambient light and allows direct viewing for easy tracking.

KODAK TECHNICAL PAN FILM 2415

P-255

DESCRIPTION

- A black-and-white, panchromatic negative film having extended red sensitivity
- Extremely fine grain and extremely high resolving power
- Ability to vary contrast through changes in development to cover a broad range of applications
- Superior pictorial film when using developers such as KODAK TECHNIDOL LC Developer or *POTA* Developer
- Dimensionally stable, 0.004-inch (0.10 mm) KODAK ESTAR-AH Base with a built-in 0.1 density that suppresses light piping
- Dyed-gel backing to suppress halation and curl
- Good latent-image keeping

TABLE OF CONTENTS

APPLICATIONS

The ease with which Technical Pan Film can be processed to a wide range of contrast levels, together with its spectral sensitization and particular combination of speed and image structure properties, makes this an unusually versatile product.

When processed to achieve wide latitude through the use of special low-contrast developers (e.g., KODAK TECHNIDOL LC and *POTA* Developers), this film is superior when used in pictorial photography. In this application, its fine grain permits enlargements at magnifications of 25X and more. In addition, its extended red panchromatic sensitivity has a haze-cutting effect when you are photographing distant landscapes or making aerial shots from helicopters or small airplanes.

When processed to high or moderately high contrast, it provides contrast reinforcement in the photomicrography of specimens which are faintly stained or colorless and normally viewed by Nomarski or other contrast-enhancing methods. It is particularly effective in chromosomal or karyotyping studies.

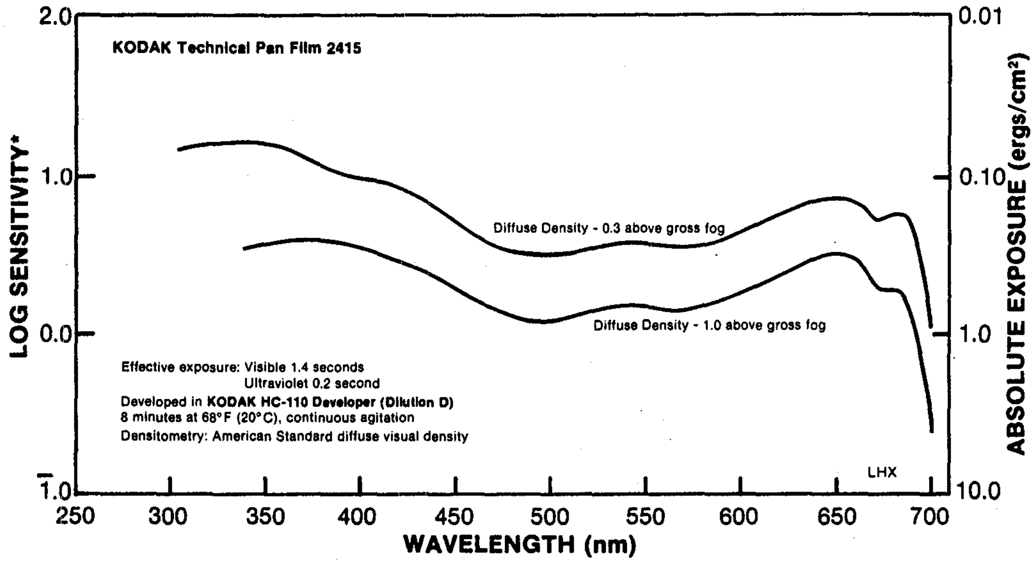
As with the precursors to this product, the extended red sensitivity and high contrast of 2415 Film are especially suited to solar photography at the H-alpha line (656 nm), but the film is also useful for lunar photography and for photographing the planets. Some investigators have used hypersensitization to extend the film range of applications to include stellar photography.

The film is an excellent choice for photographing the images reconstructed from holograms with a HeNe laser. It is equally appropriate for plotting and line-scan recording applications where the source is a HeNe laser (633 nm) or a light-emitting diode (LED) operating in the 640-660 nm range.

Technical Pan Film 2415 is useful for a variety of applications in the fields of slide-making, copying, and personal microfilming, most of which require high or moderately high contrast coupled with fine grain and high resolving power. To cite a special example of copying, the film is particularly effective for photographing electrophoretograms.

Resourceful photographers will surely find other applications where the performance characteristics and flexibility of Technical Pan Film are as valuable as in the uses mentioned here.

© Eastman Kodak Company, 1982



*Sensitivity = reciprocal of exposure (ergs/cm²) required to produce specified density

SPECTRAL SENSITIVITY

The spectral sensitivity of Technical Pan Film 2415 reflects an extensive effort to provide reasonably uniform sensitivity at all visible wavelengths out to 690 nanometres. To achieve a closer approximation to flat response, some users may wish to make exposures through a color compensating filter which selectively attenuates red and blue-UV radiation, e.g., a KODAK Color Compensating Filter CC40C or CC50C (Cyan). The effect of using such a filter will be to yield reasonably flat response out to 655 nm. Note, in comparison, that films having conventional panchromatic sensitivity are designed to provide flat response only out to 625 nm. Thus even with a CC50C Filter, Technical Pan Film 2415 will record red portions of a scene relatively more efficiently than materials such as KODAK PANATOMIC-X Film or KODAK PLUS-X Pan Film.

IMAGE STRUCTURE CHARACTERISTICS

All data given in this section are based on development at 68°F (20°C) in KODAK HC-110 Developer (Dilution D) for 8 minutes or in KODAK TECHNIDOL LC Developer for 15 minutes (as indicated).

	KODAK Developers	
	HC-110 (Dilution D)	TECHNIDOL LC
DIFFUSE RMS GRANULARITY*	8	7
RESOLVING POWER† (lines per mm)		
T.O.C. 1000:1	320	400
T.O.C. 1.6:1	125	125

Test object contrast

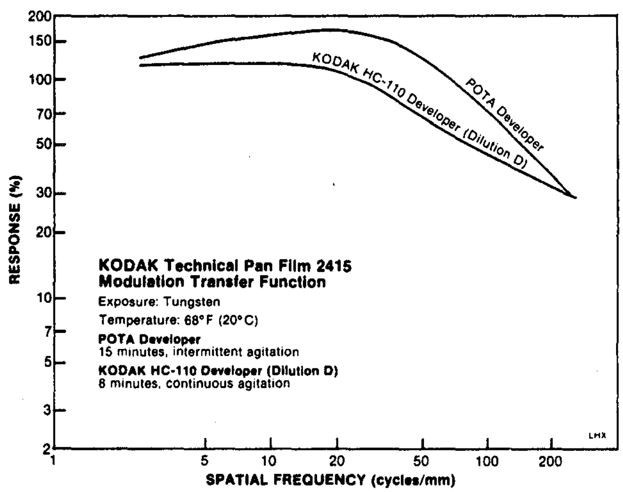
*Read at a net diffuse density of 1.0 using a 48-micrometre aperture and 12X magnification.

†Determined according to a method similar to the one described in ANSI Standard No. PH-2.33-1976, *Method for Determining the Resolving Power of Photographic Materials.*

MODULATION TRANSFER FUNCTION

These photographic modulation-transfer values were determined using a method similar to that of ANSI Standard PH-2.39-1977. The film was exposed with the specified illuminant to spatially varying sinusoidal test patterns having an aerial image modulation of a nominal 35 percent at the image plane, with processing as indicated. In most cases, these photographic modulation transfer values are influenced by development adjacency effects and are not equivalent to the true optical modulation-transfer curve of the emulsion layer in the particular photographic product.

Modulation Transfer Function



EXPOSURE

Since there is a wide range of specialized exposure conditions in which this film may be used, we give recommendations only for the most common applications. Note that the exposure index is closely related to the processing conditions and the resulting contrast. Consult the values presented with the characteristic curves in

choosing the appropriate contrast and exposure index. Exposure index values given here are for use with meters marked for ISO (ASA/DIN) speeds or exposure indexes and are suggested starting points for trial exposures.

Note:

$S°$ (logarithmic speed) $= 1 + 10 \log_{10} S$ (arithmetic speed)

i.e., "DIN" $= 1 + 10 \log_{10}$ "ASA"

Bracketing exposures by whole-stop intervals will usually be required for initial tests; use half-stop intervals for critical applications.

PICTORIAL PHOTOGRAPHY

This film yields superior image quality when processed in compensating developers such as KODAK TECHNIDOL LC Developer or *POTA* Developer. The grain and resolving power of this film are better than any other black-and-white pictorial film that Kodak has ever offered.

Because the sensitivity of this film extends further into the red region than conventional panchromatic films, the recording of red objects will be slightly lighter than normal in the print. In some cases, this characteristic may be desirable. For example, it helps reduce the effect of some types of skin blemishes and in many cases produces a luminous quality to skin tones which many observers consider quite pleasing.

Filtration is usually not required in either portrait or scenic pictorial photography. However, in some cases filtration may be required. In particular, Caucasian flesh tones in full sun may look too light and possibly pasty. This effect is less evident in shade portraits outdoors because there is less red light present. In some cases, a KODAK WRATTEN Filter No. 38 or a KODAK Color Compensating Filter CC40C used without a filter factor, may be sufficient to lessen the excess red sensitivity. Because of variations in circumstances and tastes, experimentation is in order.

KODAK TECHNIDOL LC Developer is available in a 3-packet pouch. Each packet holds enough powder to make 1 U.S. pint (473 mL) of solution sufficient to process two 135-36 size rolls of KODAK Technical Pan Film 2415. For mixing instructions, refer to the packet.

The suggested processing conditions for KODAK TECHNIDOL LC Developer with KODAK Technical Pan Film 2415 are as follows:

Exposure Index: 25 for trial exposures

(Based upon the formula EI = .81E is the 1/25 second exposure in lux seconds required for a density of .1 above minimum density.)

Development: Refer to small-tank processing section

Temperature:	68°F (20°C)	77°F (75°C)	86°F (30°C)
Time:	15 min.	11 min.	8 min.

Develop to the desired contrast index, based on the suggested starting points. The contrast index is dependent primarily upon the developer, temperature, dilution, and development time chosen. It is affected to a lesser extent by exposure time, specific processing techniques, and normal product variability. Therefore, the times given above should be considered as starting points only.

NOTE: If one of the optional higher developer temperature recommendations are used, the rinse and fix temperatures should be maintained within 3°F (1.7°C) of the developer temperature, and the wash temperature maintained within 5°F (3°C) of the developer temperature.

In addition to KODAK TECHNIDOL LC Developer, pictorial results may be obtained with this film when using *POTA* Developer. It will produce results somewhat similar to KODAK TECHNIDOL LC Developer and can be prepared as follows:

Development in Small Tank
Agitation at 30-Second Intervals

Contrast	Contrast Index	KODAK Developer	Development Time (minutes) at 68°F (20°C)	Exposure Index
High	2.50	DEKTOL	3	200
	2.25—2.50	D-19	2- 8	100/200
	1.20—2.10	HC-110 (Dil. B)	4-12	100/250
	1.00—2.10	D-76	6-12	50/125
	0.80—0.95	HC-110 (Dil. F)	6-12	32/ 64
Low	0.40—0.80	TECHNIDOL LC or *POTA*	7-18	25/ 32

Processing in KODAK VERSAMAT Film Processor, Model 11

KODAK Developer	Developer Temperature	Machine Speed (ft/min)	Developer Racks	Contrast Index	Gamma	Exposure Index
VERSAMAT 885	85°F (29.5°C)	10	1	2.20	2.80	160/23° (Daylight*)
VERSAMAT 641	85°F (29.5°C)	10	1	1.40	1.55	125/22° (Daylight*)
VERSAFLO	80°F (26.5°C)	8	2	1.80	2.30	125/22° (Tungsten†)

*Based on 1/25-second exposure time.
†Based on 1-second exposure time.

POTA Developer	
Use This Amount	**Of This Component**
1 litre	distilled or deionized water
1.5 grams	1-phenyl-3-pyrazolidinone*
30 grams	sodium sulfite

*KODAK Balancing Developing Agent, BD-84, or ILFORD PHENIDONE Developing Agent.

The suggested meter setting for trial exposures on 2415 Film to be processed with this developer in a small tank for 15 minutes at 68°F (20°C) with agitation at 30-second intervals is:

EI 25 (Daylight)

This exposure index is based on the formula EI = 0.8/E, where E is the exposure (at 1/25 second) in lux seconds required to produce a density of 0.1 above minimum density with the indicated development. Refer to the Small Tank processing for details.

PHOTOMICROGRAPHY

The following exposure index (EI) values are intended as starting points for trial exposures to give satisfactory results with photomicrography equipment having through-the-lens meters. The indexes are based on the formula EI = 10/E, where E is the 1-second exposure in lux seconds required to produce a density of 0.6 above minimum density with the indicated development.

COPY APPLICATIONS

This film can be used in many applications where KODAK High Contrast Copy Film 5069 (a discontinued product) was previously used, such as copying printed material and making reverse-text title slides.

It is recommended that two light sources be used: one on either side of the copy material and arranged so that the light strikes the material to be copied at about a 45-degree angle. For originals larger than 16 x 20 inches, four lamps (two on each side) may be needed for added and more uniform illumination.

For exposure meters marked for ISO (ASA/DIN) speeds or exposure indexes:

Tungsten—320/26°
(for incident-light readings and for reflected-light readings from *gray* card—18 percent reflectance—at the copyboard)

Tungsten—64/19°
(for reflected-light readings from *matte-white* card—90 percent reflectance—at the copyboard)

When using a through-the-lens metering camera, replace the copy with a gray card while establishing exposure; otherwise, the camera may give incorrect readings, depending on the amount of text in the copy.

The values above are intended as starting points for trial exposures and are based on development with KODAK Developer D-19 for 4 minutes at 68°F (20°C) in a small tank with agitation at 30-second intervals.

The exposure index is based on the formula EI = 36/E, where E is the 1-second exposure in lux seconds required for a density of 1.20 above minimum density with the indicated development.

As an alternative to using an exposure meter to determine exposures, the following examples can be used as starting points to obtain correct exposure: With two No. 2 photolamps in matte-surfaced reflectors at about 4 feet from the copyboard, give 1/60 second at *f*/8. With two No. 1 photolamps, exposures will be approximately twice that needed with No. 2 photolamps.

FILTER FACTORS

When through-the-lens exposure meters are used, the following filter factors should be used to correct the meter reading obtained without the indicated filter in place; if the meter is read through the filter, the filter factor will be significantly less.

KODAK WRATTEN Gelatin Filter	Filter Factor*	Filter Factor†
No. 8	1.2	1.5
No. 11	5	
No. 12	1.2	
No. 13	6	
No. 15	1.2	2.0
No. 25	2	3.0
No. 38		3.0
No. 47	25	
No. 58	12	

*Based on 1-second tungsten exposure with development for 8 minutes at 68°F (20°C) in KODAK HC-110 Developer, Dilution D.

†Based on 1/25-second daylight exposure with development for 15 minutes at 68°F (20°C) in *POTA* Developer.

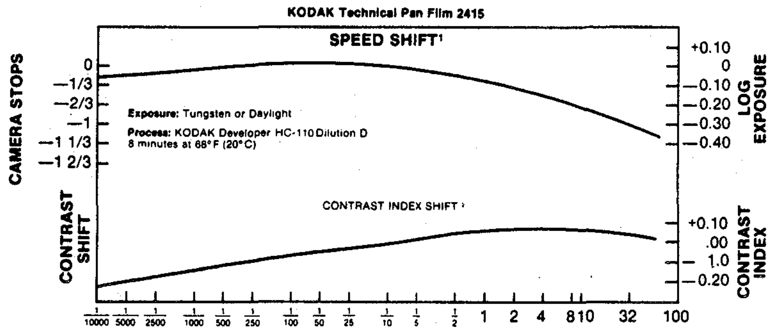
RECIPROCITY FAILURE

For exposures between 1/10,000 and 1 second, no correction in exposure conditions is required to compensate for reciprocity effects. However, for exposures shorter than 1/500 second, it may be desirable to increase development in order to compensate for the tendency towards reduced contrast with very short exposures.

Changes in Speed and Contrast Due to Reciprocity Effects

With This Exposure Time (seconds)	Increase Exposure by (lens stops) OR	Adjust Exposure Index to	Contrast Index Changes by This Amount
1/10,000	None	125	-0.20
1/1,000	None	125	-0.15
1/100	None	125	-0.05
1/10	None	125	0
1	None	125	+0.07
10	+ ⅔	80	+0.07
100	+1⅓	50	0

Based on development in KODAK HC-110 Developer (Dilution D) for 8 minutes at 68°F (20°C) with agitation at 30-second intervals.



[1]At a density 0.10 above gross fog.

[2]At a density of 0.10 above gross fog and +2.00 log exposure range.

PROCESSING

SMALL-TANK PROCESSING

In some cases, particularly when you are processing with spiral reels, this film may be susceptible to nonuniform processing effects especially when using compensating developers such as *POTA*. To avoid these effects, do not pour the developers in the top of the tank. First fill the tank, then drop the reel smoothly and without interruption into the solution. This action not only promotes more uniform development but also helps prevent the formation of bubbles or air bells. Rap the tank a few times initially to dislodge air bells that may have formed and agitate slightly all within the first 5 seconds. Cover the tank, and let it settle for 25 seconds. Avoid overagitation in the first 30 seconds. Thereafter, agitate the film gently by using 3 to 5 inversion cycles for 5 seconds every 30 seconds and finish processing in the normal manner. Experimentation will reveal the best method.

Before using these developers, make sure that the solution is free of small air bubbles which, if they adhere to the emulsion surface, may cause small undeveloped clear spots on the film—dark spots on the print. Bubbles may form more easily if cold and hot water are mixed together; if bubbles do form, let the developer stand until they dissipate. Attaching an aerator to the water supply will help form very large bubbles which will rise immediately to the liquid surface without remaining in solution.

For processing in small tanks with spiral reels and agitation at 30-second intervals, use the following sequence:

Develop to the desired contrast index based on information in the exposure section and on the characteristic curves. The contrast index obtained depends primarily upon the developer, temperature, dilution, and development time chosen. It is affected to a lesser extent by exposure time (see Reciprocity Failure), specific processing techniques, and normal product variability. Therefore, the times given should be considered as starting points only.

Rinse at 65 to 70°F (18.5 to 21°C) in KODAK Indicator Stop Bath, KODAK Stop Bath SB-1a, or KODAK Stop Bath SB-5 for 15 to 30 seconds. Use running water for 30 seconds if no stop bath is used.

Fix at 65 to 70°F (18.5 to 21°C), with frequent agitation.

KODAK Rapid Fixer	1½ to 3 minutes
KODAK Fixer	2 to 4 minutes
KODAK Fixing Bath F-5	2 to 4 minutes

Wash in clear, running water at 65 to 70°F (18.5 to 21°C) for 5 to 15 minutes, depending upon reduction of residual hypo needed.

To save time and conserve water, KODAK Hypo Clearing Agent can be used. Rinse the fixed film in running water for 15 seconds. Next bathe the film in KODAK Hypo Clearing Agent for 30 seconds with agitation. Then wash the film for 1 minute in running water at 65 to 70°F (18.5 to 21°C), allowing at least one change of water during this time.

Dry in a dust-free place. Heated forced air at 120 to 140°F (49 to 60°C) may be used to reduce drying time.

MACHINE PROCESSING

Using the KODAK VERSAMAT Film Processor, Model 11, and the listed chemicals, follow one of the processing sequences described here. For the three processing sequences, fixing and drying are adequate at the recommended machine speeds. The user should run tests to determine that washing quality is adequate.

KODAK VERSAMAT 641 Developer Replenisher
KODAK VERSAMAT 641 Developer Starter
KODAK VERSAMAT 641 Fixer and Replenisher

Processing Sequence

Step	No. of Racks	Path Length	Temperature
Develop	1	4 ft (1.2 m)	85 ± 1/2°F (29.5 ± 0.3°C)
Fix	3	12 ft (3.7 m)	85°F (29.5°C) nominal
Wash	2	8 ft (2.4 m)	75 to 80°F (24 to 27°C)
Dry	-	8 ft (2.4 m)	135 to 140°F (57 to 60°C)

To produce a contrast index of about 1.4, start with a machine speed of 10 feet per minute (3.05 m/min).

KODAK VERSAMAT 885 Developer Replenisher
KODAK VERSAMAT 885 Developer Starter
KODAK VERSAMAT 885 Fixer and Replenisher

Processing Sequence

Step	No. of Racks	Path Length	Temperature
Develop	1	4 ft (1.2 m)	85 ± 1/2°F (29.5 ± 0.3°C)
Fix	3	12 ft (3.7 m)	85°F (29.5°C) nominal
Wash	2	8 ft (2.4 m)	75 to 80°F (24 to 27°C)
Dry	-	8 ft (2.4 m)	135 to 140°F (57 to 60°C)

To produce a contrast index of about 2.2, start with a machine speed of 10 feet per minute (3.05 m/min). Adequate washing is obtained at speeds up to 15 feet per minute (4.5 m/min).

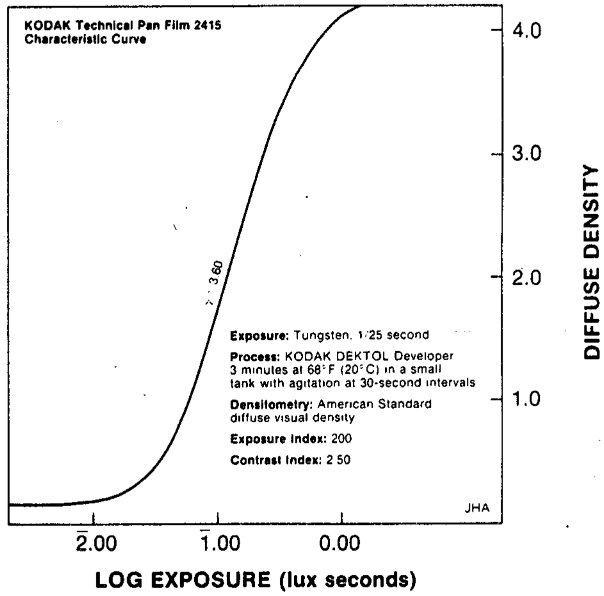
KODAK VERSAFLO Developer Replenisher
KODAK VERSAFLO Developer Starter
KODAK Rapid Fixer

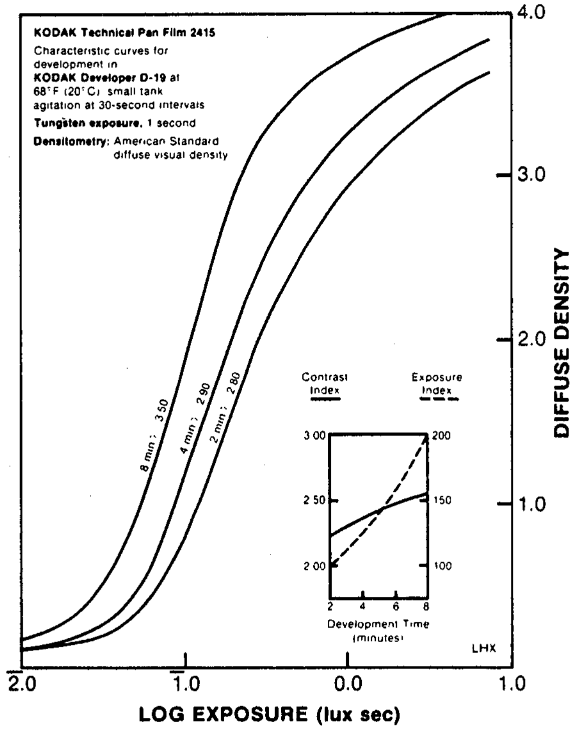
Processing Sequence

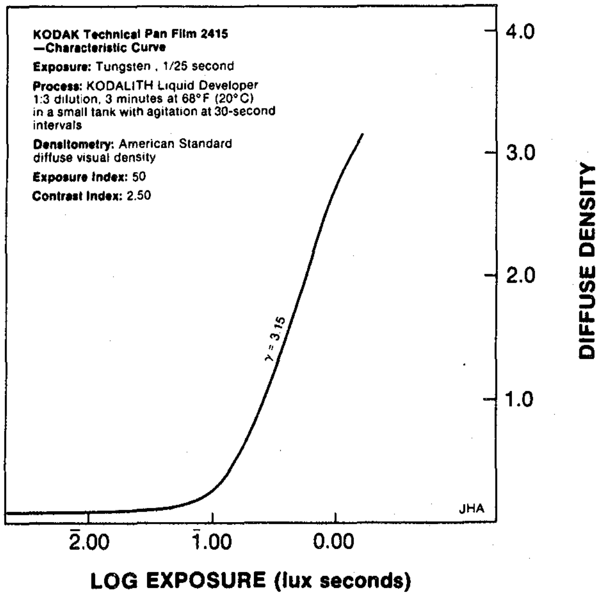
Step	No. of Racks	Path Length	Temperature
Develop	2	8 ft (2.4 m)	80 ± 1/2°F (26.5 ± 0.3°C)
Fix	3	12 ft (3.7 m)	80°F (27°C) nominal
Wash	2	8 ft (2.4 m)	70 to 75°F (21 to 24°C)
Dry	-	8 ft (2.4 m)	135 to 140°F (57 to 60°C)

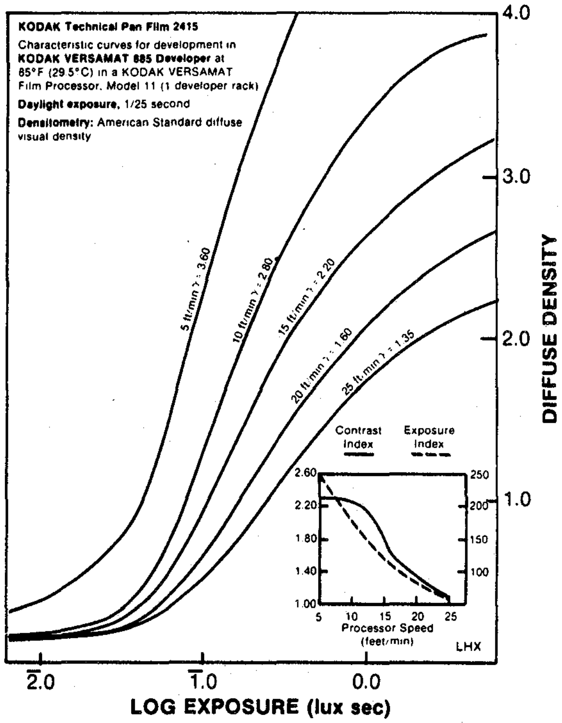
To produce a contrast index of about 1.8, start with a machine speed of 8 feet per minute (2.4 m/min). Washing is not sufficient to provide archival quality but should be adequate for many scientific recording applications. Transport difficulties may be encountered when processing sheet or short strips of film in VERSAFLO Developer.

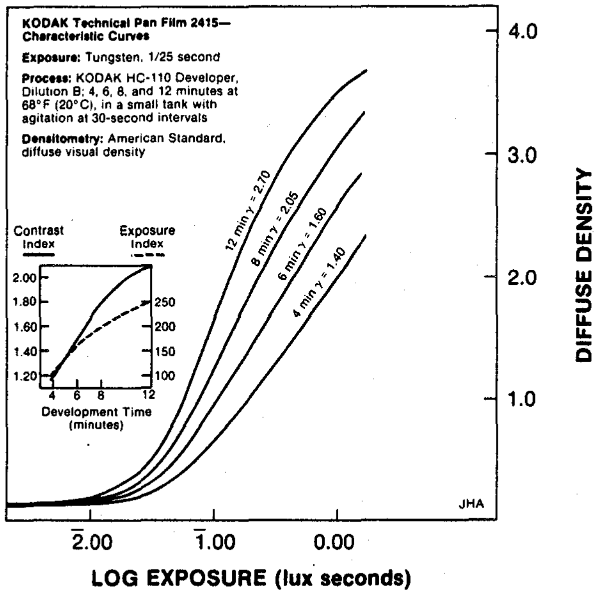
CHARACTERISTIC CURVES

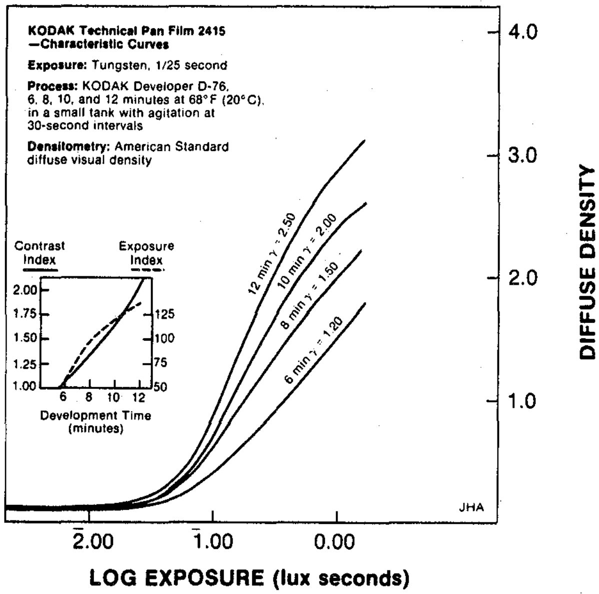


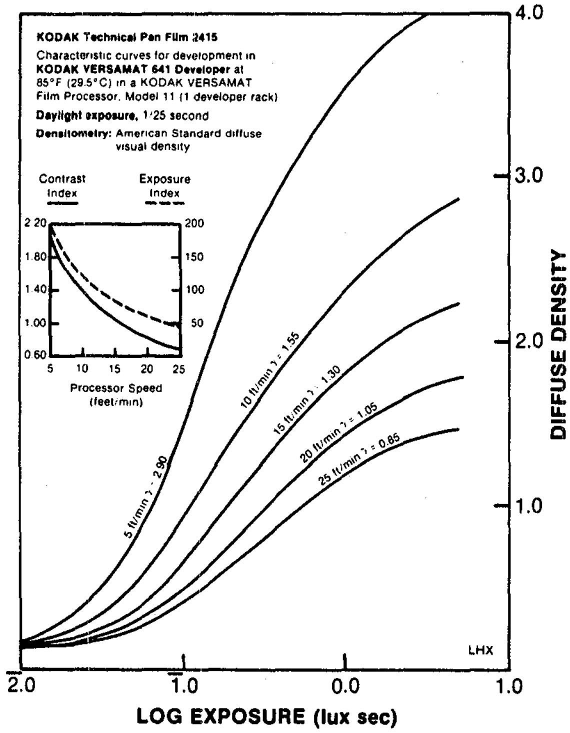


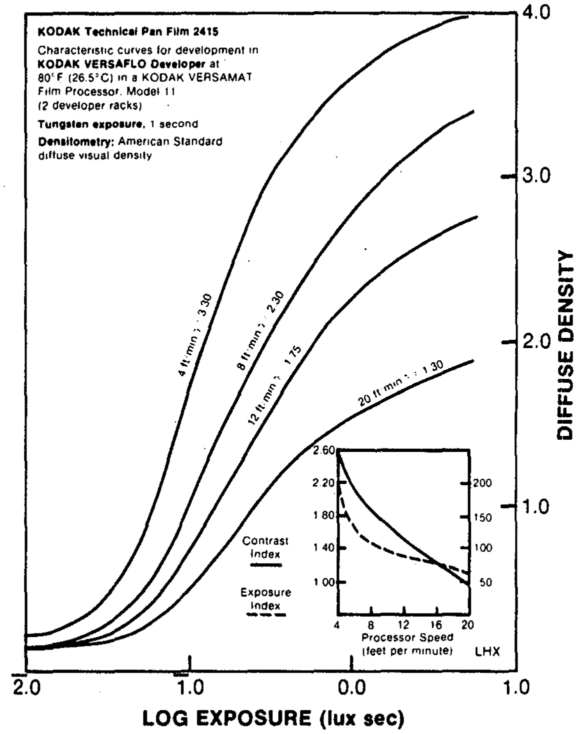

KODAK Technical Pan Film 2415
—Characteristic Curve
Exposure: Tungsten , 1/25 second
Process: KODALITH Liquid Developer 1:3 dilution, 3 minutes at 68°F (20°C) in a small tank with agitation at 30-second intervals
Densitometry: American Standard diffuse visual density
Exposure Index: 50
Contrast Index: 2.50
γ = 3.15
4.0
3.0
2.0
1.0
DIFFUSE DENSITY
JHA
$\bar{2}$.00
$\bar{1}$.00
0.00
LOG EXPOSURE (lux seconds)

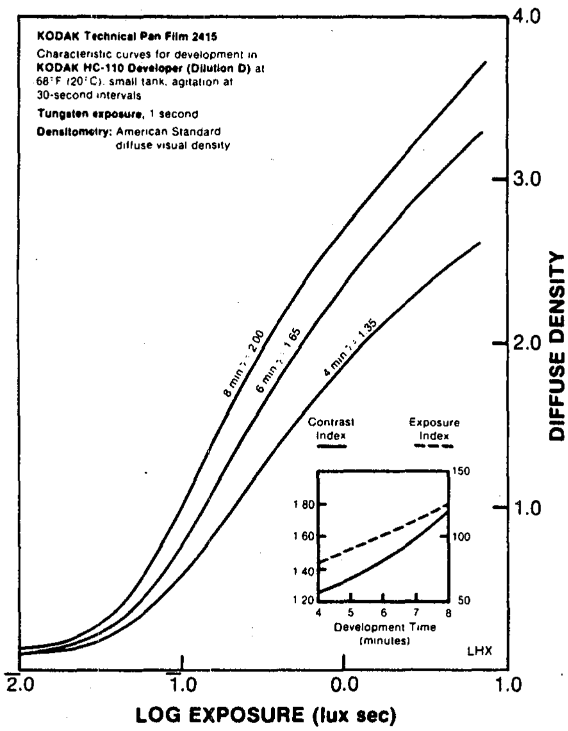

KODAK Technical Pan Film 2415
Characteristic curves for development in KODAK VERSAMAT 885 Developer at 85°F (29.5°C) in a KODAK VERSAMAT Film Processor, Model 11 (1 developer rack)
Daylight exposure, 1/25 second
Densitometry: American Standard diffuse visual density
5 ft/min γ = 3.60
10 ft/min γ = 2.80
15 ft/min γ = 2.20
20 ft/min γ = 1.60
25 ft/min γ = 1.35
Contrast Index
Exposure Index
2.60
2.20
1.80
1.40
1.00
250
200
150
100
5
10
15
20
25
Processor Speed (feet/min)
LHX
4.0
3.0
2.0
1.0
DIFFUSE DENSITY
$\bar{2}$.0
$\bar{1}$.0
0.0
LOG EXPOSURE (lux sec)

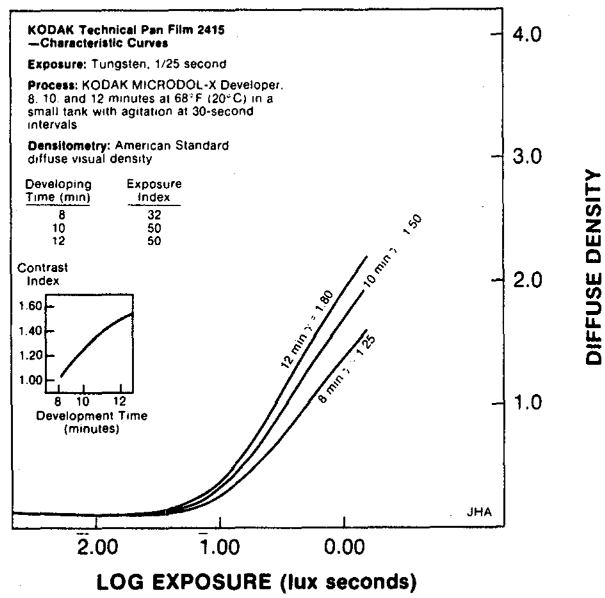

KODAK Technical Pan Film 2415—
Characteristic Curves
Exposure: Tungsten, 1/25 second
Process: KODAK HC-110 Developer, Dilution B; 4, 6, 8, and 12 minutes at 68°F (20°C), in a small tank with agitation at 30-second intervals
Densitometry: American Standard, diffuse visual density
Contrast Index
Exposure Index
2.00
1.80
1.60
1.40
1.20
250
200
150
100
4
6
8
12
Development Time (minutes)
12 min γ = 2.70
8 min γ = 2.05
6 min γ = 1.60
4 min γ = 1.40
4.0
3.0
2.0
1.0
DIFFUSE DENSITY
JHA
$\bar{2}$.00
$\bar{1}$.00
0.00
LOG EXPOSURE (lux seconds)

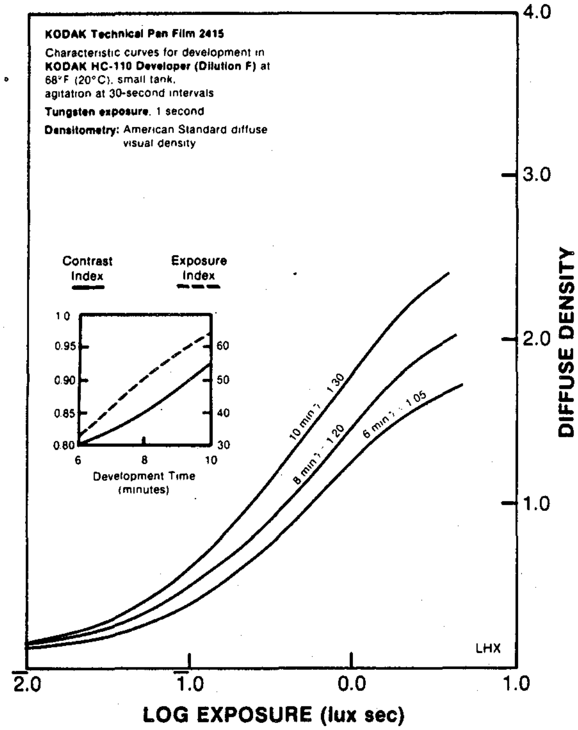

KODAK Technical Pan Film 2415
—Characteristic Curves
Exposure: Tungsten, 1/25 second
Process: KODAK Developer D-76, 6, 8, 10, and 12 minutes at 68°F (20°C), in a small tank with agitation at 30-second intervals
Densitometry: American Standard diffuse visual density
Contrast Index
Exposure Index
2.00
1.75
1.50
1.25
1.00
125
100
75
50
6
8
10
12
Development Time (minutes)
12 min γ = 2.50
10 min γ = 2.00
8 min γ = 1.50
6 min γ = 1.20
4.0
3.0
2.0
1.0
DIFFUSE DENSITY
JHA
$\bar{2}$.00
$\bar{1}$.00
0.00
LOG EXPOSURE (lux seconds)

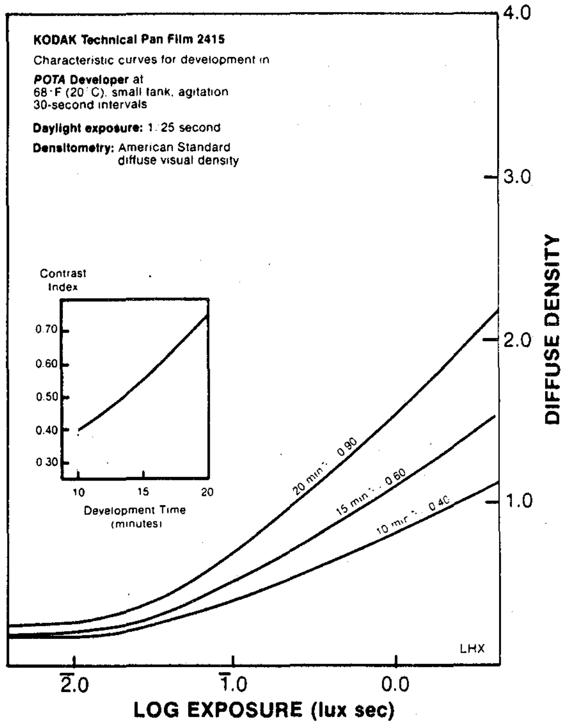

KODAK Technical Pan Film 2415
Characteristic curves for development in KODAK VERSAMAT 641 Developer at 85°F (29.5°C) in a KODAK VERSAMAT Film Processor, Model 11 (1 developer rack)
Daylight exposure, 1/25 second
Densitometry: American Standard diffuse visual density
Contrast Index
Exposure Index
Processor Speed (feet/min)
5 (ft/min) : 2.90
10 (ft/min) : 1.55
15 (ft/min) : 1.30
20 (ft/min) : 1.05
25 (ft/min) : 0.85
LHX
DIFFUSE DENSITY
LOG EXPOSURE (lux sec)

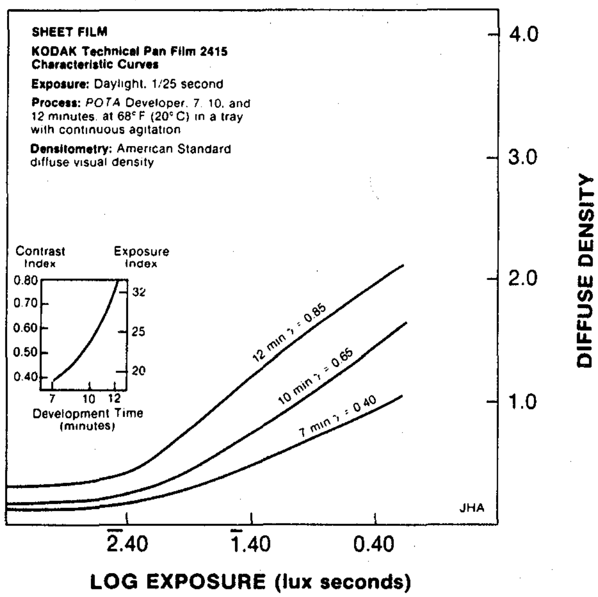

KODAK Technical Pan Film 2415
Characteristic curves for development in KODAK VERSAFLO Developer at 80°F (26.5°C) in a KODAK VERSAMAT Film Processor, Model 11 (2 developer racks)
Tungsten exposure, 1 second
Densitometry: American Standard diffuse visual density
4 (ft/min) : 3.30
8 (ft/min) : 2.30
12 (ft/min) : 1.75
20 (ft/min) : 1.30
Contrast Index
Exposure Index
Processor Speed (feet per minute)
LHX
DIFFUSE DENSITY
LOG EXPOSURE (lux sec)

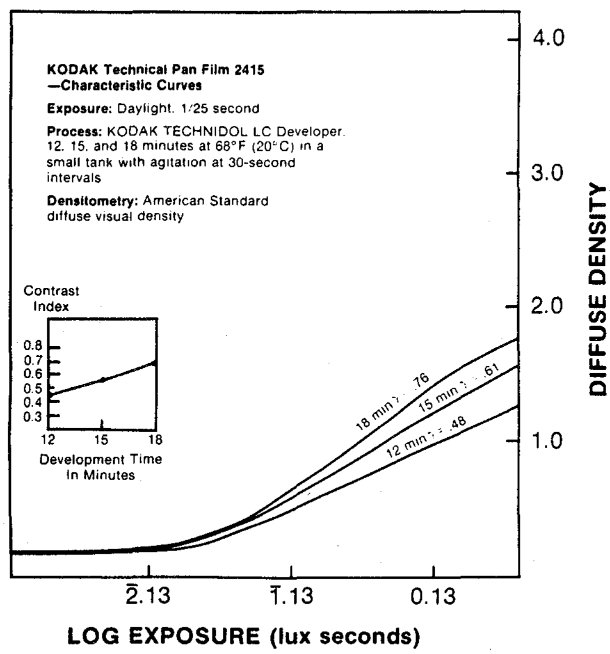

KODAK Technical Pan Film 2415
Characteristic curves for development in KODAK HC-110 Developer (Dilution D) at 68°F (20°C), small tank, agitation at 30-second intervals
Tungsten exposure, 1 second
Densitometry: American Standard diffuse visual density
8 (min) : 2.00
6 (min) : 1.65
4 (min) : 1.35
Contrast Index
Exposure Index
Development Time (minutes)
LHX
DIFFUSE DENSITY
LOG EXPOSURE (lux sec)


KODAK Technical Pan Film 2415
—Characteristic Curves
Exposure: Tungsten, 1/25 second
Process: KODAK MICRODOL-X Developer, 8, 10, and 12 minutes at 68°F (20°C) in a small tank with agitation at 30-second intervals
Densitometry: American Standard diffuse visual density
Developing Time (min) | Exposure Index
8 | 32
10 | 50
12 | 50
Contrast Index
Development Time (minutes)
12 (min) : 1.80
10 (min) : 1.50
8 (min) : 1.25
JHA
DIFFUSE DENSITY
LOG EXPOSURE (lux seconds)









The sensitometric curves and data in this publication represent product tested under the conditions of exposure and processing specified. They are representative of production coatings and, therefore, do not apply directly to a particular box or roll of photographic material. They do not represent standards or specifications which must be met by Eastman Kodak Company. The Company reserves the right to change and improve product characteristics at any time.

PRINTING

The 0.1 neutral density built into ESTAR-AH Base is approximately half that found in conventional 35 mm picture-taking films. It follows that pictorial negatives which have been given optimum exposure and processing may appear to be "thinner" than normal. It is important to take this factor into account when judging the printability of negatives.

The extremely fine grain of 2415 Film invites printing at higher magnifications than are usually considered acceptable with conventional picture-taking films. Enlargements made at magnifications greater than 25X with highly specular (point source) enlargers will be marred by a random distribution of poorly defined white specks in otherwise dense areas. The specks are caused by tiny matte particles which we find necessary to coat on the back surface of the film. Their presence can be masked with little loss in overall sharpness of the image by using an enlarger having a diffuse or semi-diffuse illumination system.

HANDLING AND STORAGE

Store unexposed film at 70°F (21°C) or lower in the original sealed container. Aging effects are lessened by storing the film at lower temperatures. If film has been refrigerated, allow the package to reach room temperature for 2 to 3 hours before opening; if frozen, allow 5 hours.

Load and unload the camera in subdued light, and rewind the film completely into the magazine before unloading the camera. For best results, process the film as soon as possible after exposure.

When handling sheet sizes of KODAK Technical Pan Film 2415 it is important to remember that it is coated on a support (ESTAR-AH Base) which has approximately half the thickness of the bases commonly used in sheet films in the days when most sheet film holders were being designed. To be sure of proper film location in the holder, it is a good idea to use a backing sheet made by exposing and processing a sheet of the 2415 Film to maximum density. The backing sheet should be clipped at all four corners to provide easy identification when loading and unloading film holders with 2415 Film in total darkness. The support thickness of this product should be kept in mind also when processing sheets either manually or in machine processors.

Total darkness is required when removing the film from the magazine or in loading and unloading film holders, and in processing. However, after development is half completed, a suitable safelight lamp with a 15-watt bulb and a KODAK Safelight Filter No. 3 (dark green) can be used for a few seconds if the safelight is kept at least 4 feet (1.2 metres) from the film.

Store processed film in a cool, dry place.

FILM SIZES AND ORDERING INFORMATION

Three sizes are listed and are available in single units through dealers who regularly supply Kodak products to professional photographers. In addition, the 135-36 size is available through dealers who carry Kodak products for general picture-taking. If your dealer does not have the film in stock, it can be ordered for you.

Size & Specification	CAT No.
135-36 magazine	129 7563
35 mm x 150 ft	
Sp 651 (Type AA core, KS perf)	129 9916
4 x 5-inch, 50 sheets per pkg	152 4594

Because this film has a thinner base than conventional 35 mm picture-taking films, 150-foot rolls finished to Sp 651 will fit in bulk-film loaders designed to accept 100-foot rolls. The 4 x 5-inch sheet film package contains two hermetically sealed envelopes, each holding 25 sheets.

Other sizes are available on a special order, subject to manufacturing limitations and prevailing minimum order requirements. Minimum order quantities for special-order sizes correspond generally to 750 square feet of film.

ADDITIONAL INFORMATION

To obtain additional information regarding KODAK Technical Pan Film 2415, its availability in special-order sizes, and ways to optimize its performance in specific applications (e.g., photomicrography, astrophotography, copying, pictorial photography), please write in reasonable detail to:

Scientific and Technical Photography
Customer Technical Services
Eastman Kodak Company
343 State Street
Rochester, New York 14650

The Kodak materials described in this publication for use with KODAK Technical Pan Film 2415 are available from those dealers normally supplying Kodak photographic products.

Consumer/Professional & Finishing Markets
EASTMAN KODAK COMPANY • ROCHESTER, NEW YORK 14650

KODAK Technical Pan Film 2415
KODAK Pamphlet No. P-255

Reprint 11-82-AE
Printed in the United States of America

KODAK, KODALITH, D-76, MICRODOL-X, DEKTOL, TECHNIDOL, ESTAR-AH, PANATOMIC-X, PLUS-X, HC-110, D-19, VERSAMAT, VERSAFLO, and WRATTEN are trademarks.

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APPENDIX D

SHUTTLE QUALIFIED LAMP

This appendix describes lamps that are already qualified for operation on the Shuttle Orbiter. These lamps represent available types. Discussions with ILC indicate that a similar lamp can be developed for the Free Surface Induced Phenomena experiment.

ILC Technology

399 Java Drive • Sunnyvale, California 94086
408-745-7900 • TWX 910-339-9389

POSITION AND TYPES OF INTERIOR CABIN LIGHTS
MC 434-0068

CONFIGURATION	LOCATION	S/S QTY
-0009	MID DECK PANEL	2
-0011	AFT STATION	1
-0014	GENERAL LIGHTING	9
-0015	MISSION SPECIALIST	1
-0016	PAYLOAD SPECIALIST	1
-0019	AIR LOCK	2
-0020	AIR LOCK	2
-0021	CMDR OVERHEAD	2
	BUNK LIGHT	4
-0022	PILOT OVERHEAD	1
-0023	GLARESHIELD	2
-0024	GLARESHIELD	1
-0025	GLARESHIELD	1
-0026	GLARESHIELD BALLAST	2

INTERIOR LIGHT ASSEMBLIES

* DEVELOPED AND QUALIFIED FOR SHUTTLE PROGRAM
* SPECIAL PROCESS CONTROLLED FLOURESCENT LAMP SOURCES
* QUALIFIED CIRCUITS FEATURING
  - DIMMING CONTROLS
  - NO VISUAL LAMP FLICKER
  - MEETS EMI REQS
  - ALL ENVIRONMENTAL REQS
* NO HAZARDOUS MATERIAL CONTAMINATION
* LONG LIFE, SUBSTANTIAL START/RE-START CAPABILITY
* LOW POWER OPERATION

INTERIOR LIGHT ASSEMBLY SPECIFICATION

	-9	-11	-14	-15/-16	-19/-20	-21/-22	-23*	-24/-25*
INPUT VOLTAGE	28.0 VDC	DO	DO	DO	DO	DO	DO	DO
PWR CONSUMP	6.6W	19.0W	16.5W	33.0W	16.5W	16.5W	11.0W	11.0W
LAMPS/ASSY	1	1	1	2	1	1	2	2
LAMP LG (IN)	6	18	18	11	9	9	6	6
PK FT CANDLES (AT 3FT)	2.5	12.5	12.5	28.0	9.0	9.0	4.0	4.0
COLOR TEMP	4200^{0}K	DO	DO	DO	DO	DO	DO	DO
CIE COORDINATES	X=.37	DO	DO	DO	DO	DO	DO	DO
	Y=.39	DO	DO	DO	DO	DO	DO	DO
	$\pm$ .02	DO	DO	DO	DO	DO	DO	DO
DIMMING CONTROL	NO	YES	NO	YES	NO	YES	YES	YES
BY	N/A	ELECT	N/A	ELECT	N/A	MNL	ELECT	ELECT
LAMP FLICKER	NONE	DO	DO	DO	DO	DO	DO	DO
LAMP LEAK RT (NTE)	1×10^{-5}	DO	DO	DO	DO	DO	DO	DO
OPR LIFE (ASSY/HRS)	12,800	DO	DO	DO	DO	DO	DO	DO
OPR LIFE (LAMP/HRS)	6,000 AT 60%	DO	DO	DO	DO	DO	DO	DO
OPR TEMP	0^{0}F TO $+140^{0}$F	DO	DO	DO	DO	DO	DO	DO
NON-OPR TEMP	-65^{0}F TO $+150^{0}$F	DO	DO	DO	DO	DO	DO	DO
VIBRATION	LVL B	LVL A	LVL B	LVL A	LVL A	LVL A	LVL B	LVL B
WEIGHT (LBS)	1.0	4.5	4.0	3.0	3.0	3.5	1.0	1.0

* OPERATED BY REMOTELY LOCATED BALLAST (-0026)

VIBRATION

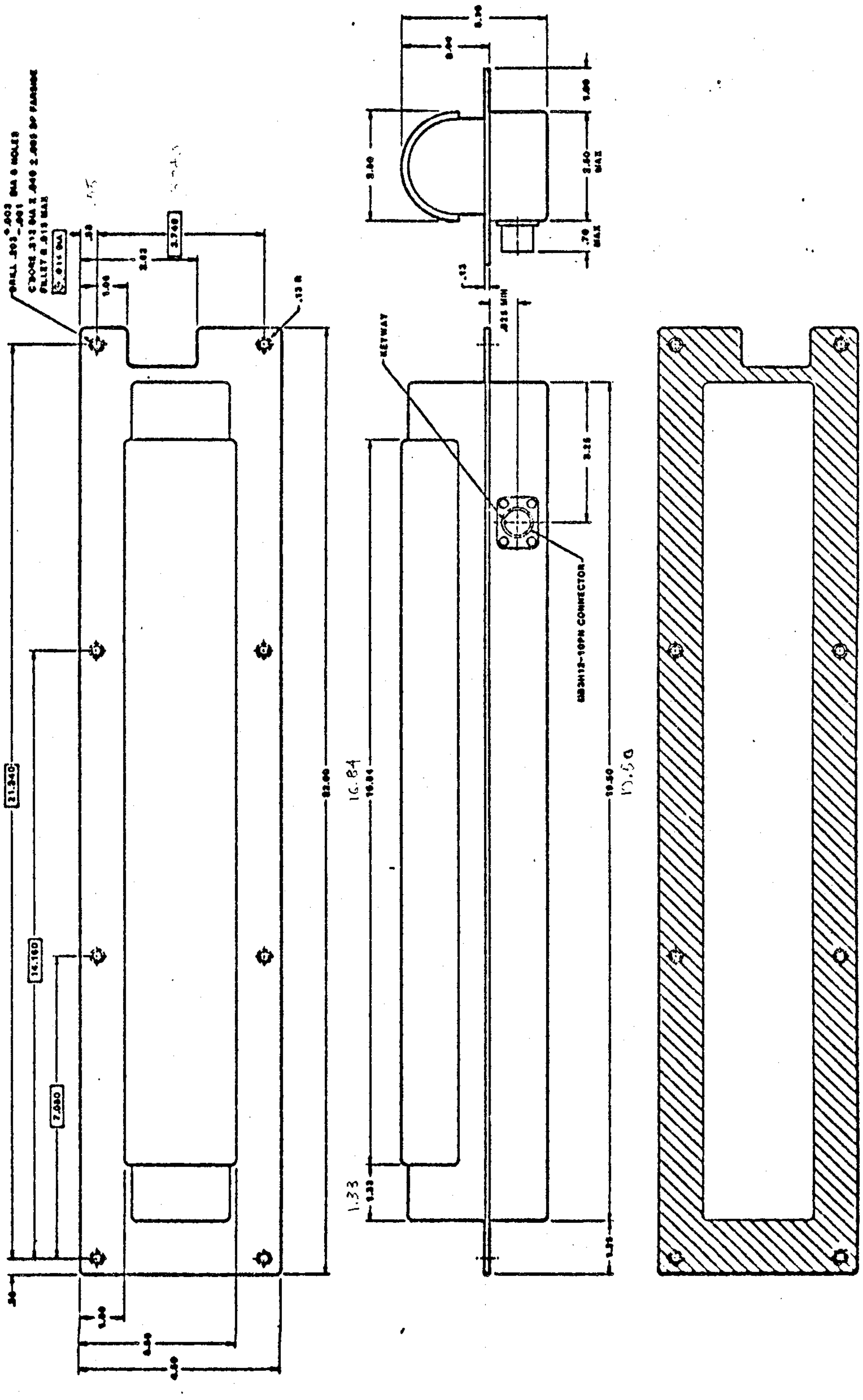
Hz	LEVEL A
20-150	+6dB/OCTAVE TO 0.2 g^2/Hz
150-300	CONST AT 0.2 g^2/Hz
300-400	-6dB/OCTAVE TO 0.12 g^2/Hz
400-1000	CONST AT 0.12 g^2/Hz
1000-2000	-9dB/OCTAVE FR 0.12 g^2/Hz

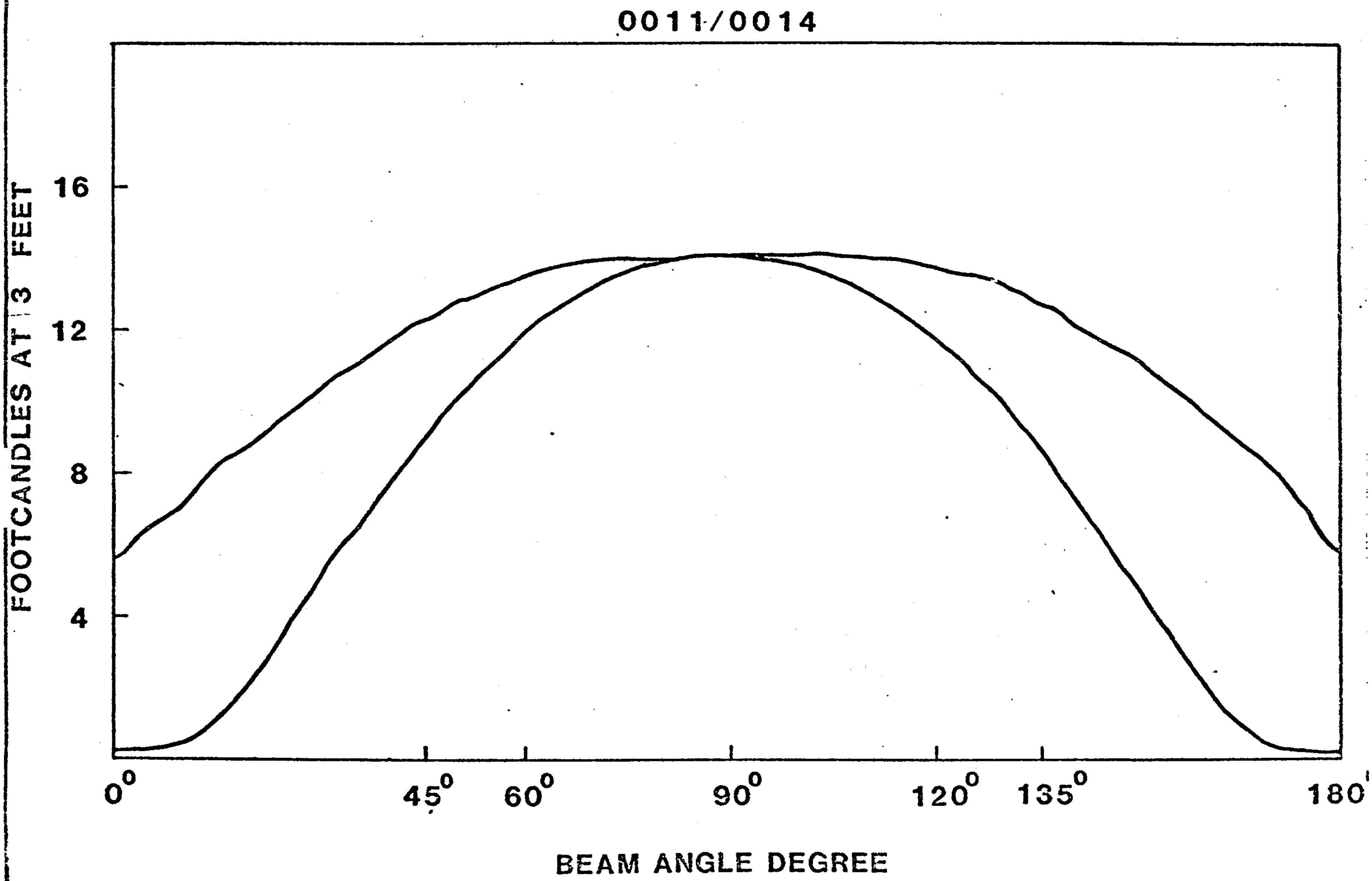
DURATION 48 MIN/AXIS

Hz	LEVEL B
20-150	+5dB/OCTAVE TO 0.09 g^2/Hz
150-900	CONST AT 0.09 g^2/Hz
900-2000	-9dB/OCTAVE FR 0.09 g^2/Hz

DURATION 48 MIN/AXIS

-0011 CONFIGURATION


KEYWAY
21.940
14.160
7.080
22.00
16.84
19.50


0011/0014
FOOTCANDLES AT 3 FEET
16
12
8
4
0°
45°
60°
90°
120°
135°
180°
BEAM ANGLE DEGREE

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APPENDIX E

Accelerometer Data

An accelerometer is optional for the Free Surface Induced Phenomena Experiment. This appendix describes the ACIP/HIRAP system that provides an accelermeter capable of measuring to the μg level.

kms

inc. A Subsidiary of KMS Industries, Inc.
3621 South State Road, P.O. Box 1567, Ann Arbor, Michigan 48106 313/769-8500

83-AERO-0150
22 March 1983

Mr. Jack Kropp
Sr. Project Engineer
Advanced Technology Group
Bldg. R1, Rm 2216
TRW-STG, One Space Park
Redondo Beach, CA 90278

Dear Jack,

As a followup to our telecon of 21 March regarding Shuttle-qualified micro-g accelerometer systems, I have enclosed a brochure describing our ACIP/HIRAP system and a possible block diagram for a modified HIRAP system conforming with your requirement. In the block diagram, the HIRAP package would provide triaxial accelerometer outputs over the range of one micro-g to 8 milli-g with corrected long term stability on the order of one micro-g. Changes in scaling and dynamic range are possible with minor modifications

The existing Mini-Data Handling Electronics (DHE) assembly was designed to accept 6 channels of Orbiter control surface transducers but could be adapted to the HIRAP-only configuration for cost savings. I believe that only an additional formatter card would be required as new hardware to replace the PCM Master Formatter that we currently use for our 18 channel system.

Since both the HIRAP and Mini-DHE are Shuttle flight qualified and currently installed on Challenger for STS-6, I would expect only minimal qualification would be required for your mid-deck experiment implementation.

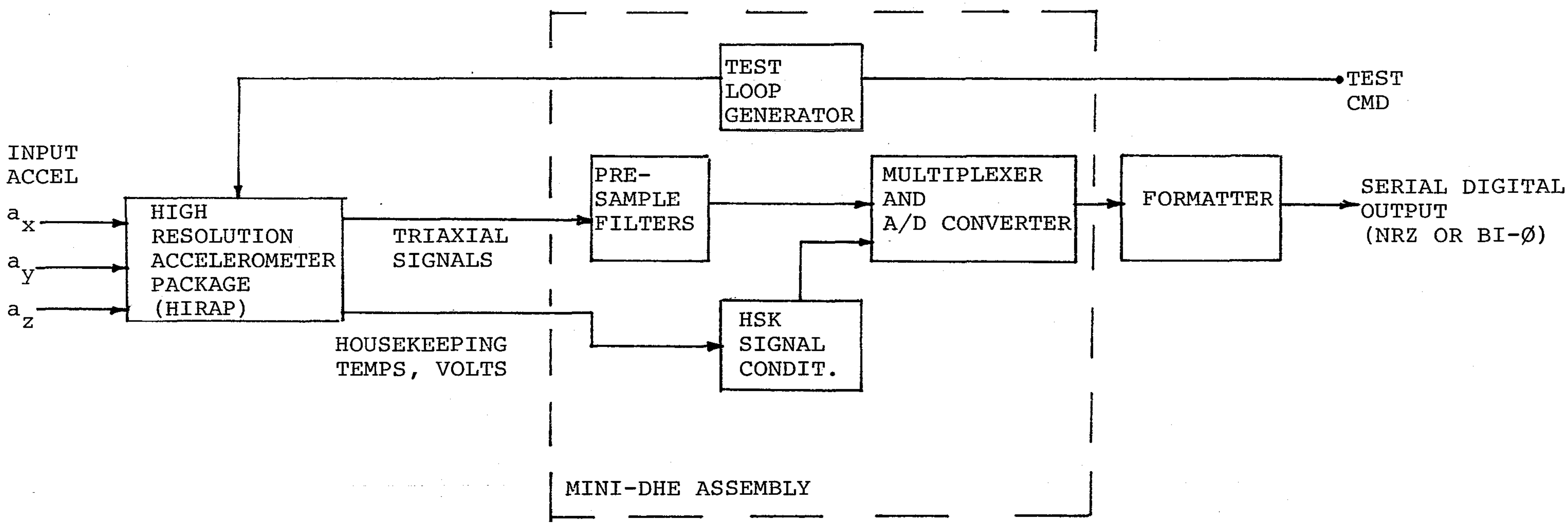
For your budgetary planning purposes, the complete triaxial system with a Mini-DHE as shown in the block diagram has a rough order of magnitude (ROM) cost of 175K based upon minimal test and qualification. If I can assist you with further definition or information for your application, please contact me at 313 769 8500, ext 251.

Very best regards,

Jim Fox

James C. Fox
NASA Program Mgr.
Aerospace Technology Group

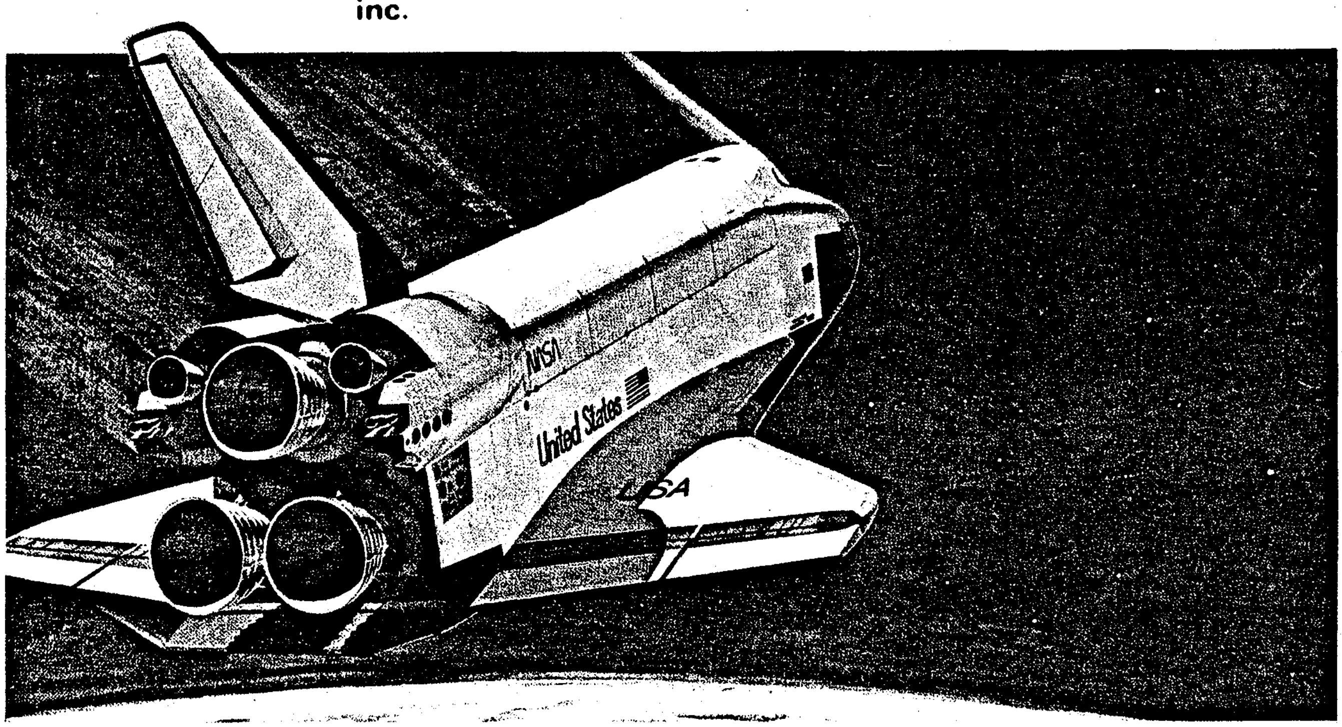
JCF:sh



MID-DECK EXPERIMENT ACCELEROMETER SYSTEM

Space Transportation and
kms Aerospace Technology

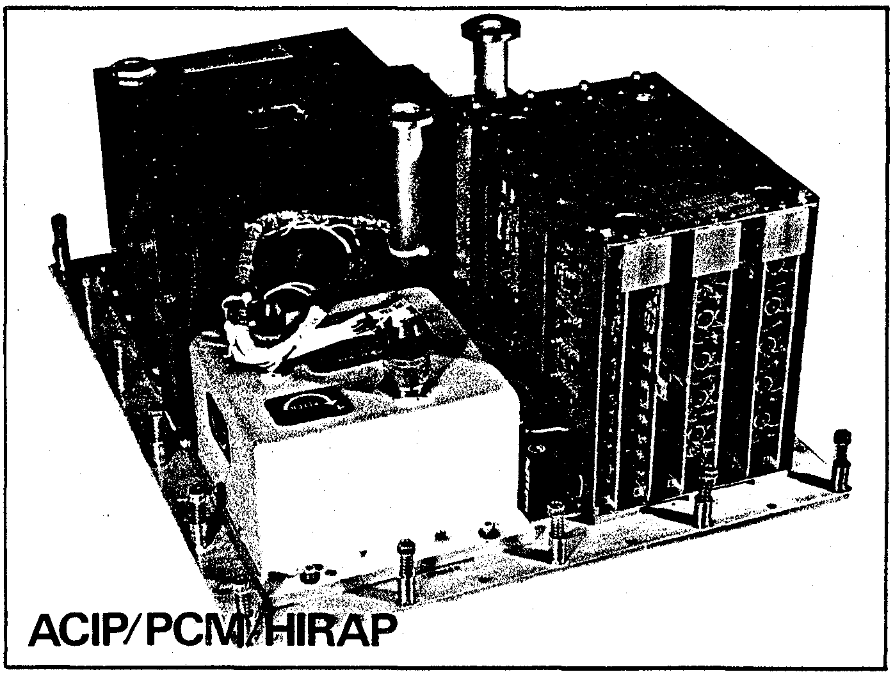
inc.



Aerodynamic
Coefficient
Identification
Package

Pulse
Code
Modulation
System

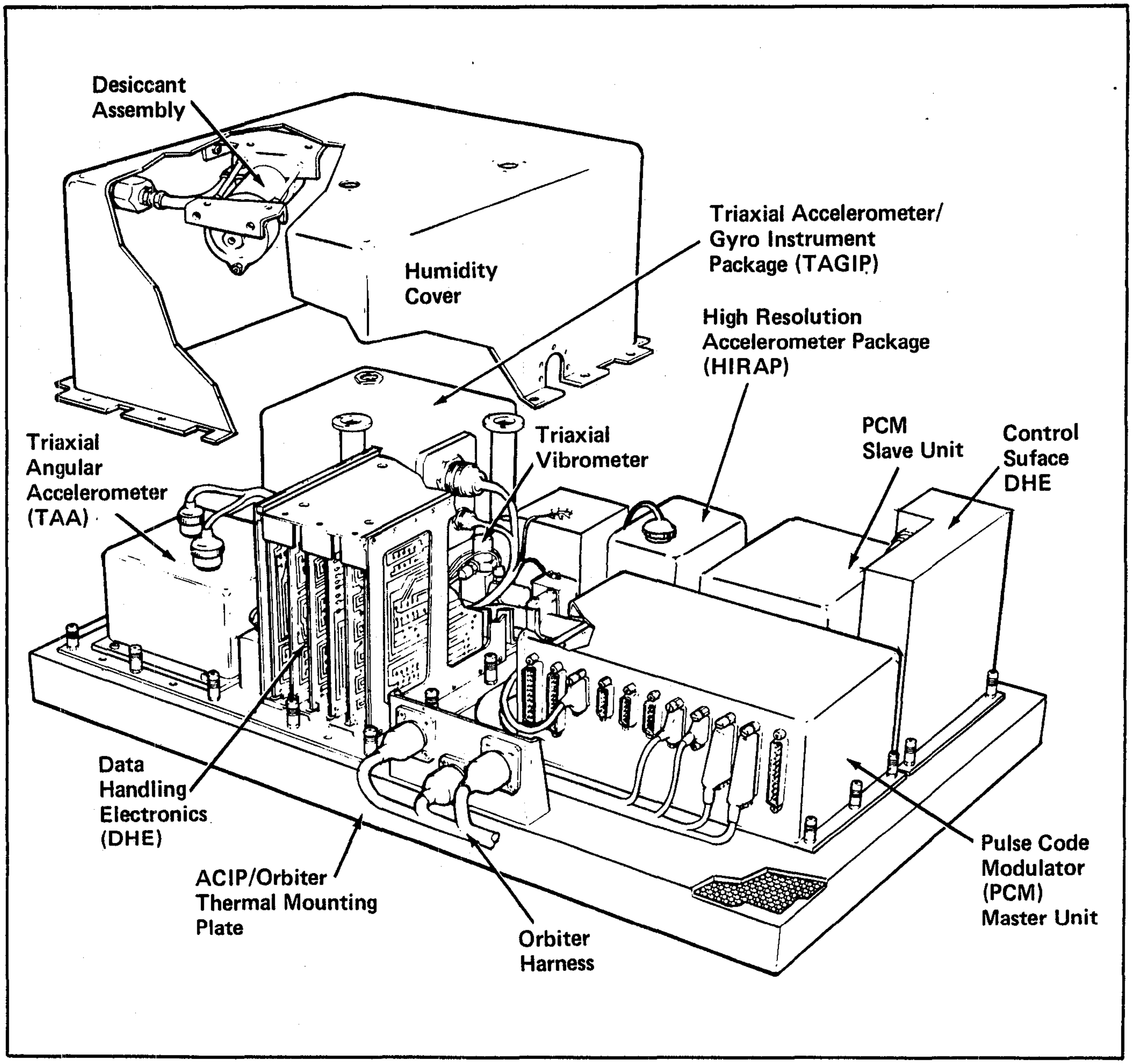
High Resolution
Accelerometer
Package



—A Flexible, Growth Oriented System

ACIP/PCM/HIRAP

...Designed for Future Expansion



The primary objective of the Aerodynamic Coefficient Identification Package (ACIP) and the High Resolution Accelerometer Package (HIRAP) is to acquire accurate measurements of orbiter rates and accelerations during the critical reentry and atmospheric descent phases. By obtaining this information, uncertainties concerning orbiter behavior will be significantly reduced. Thus, in the future, it may be possible for spacecraft to perform new maneuvers, carry bigger payloads, and remain in orbit for longer periods of time.

The Pulse Code Modulation (PCM) System provides the digital data formatting and encoding required to transfer the digitized ACIP/HIRAP sensor data to the Shuttle tape recorder. Post-flight data tapes are analyzed by NASA scientists and engineers to derive the Shuttle aerodynamic, stability and control performance parameters associated with each flight.

The ACIP/PCM system was initially installed on Columbia and has provided critical flight data measurements for each Development Flight Instrumentation (DFI) Shuttle mission.

The ACIP/PCM/HIRAP system has been installed on Challenger and will be utilized to additionally measure the micro-g accelerations on-orbit and during initial reentry. Although ACIP/PCM/HIRAP was designed for, and utilized by, the Shuttle Orbiter Experiments Program, many basic features are applicable to other space-based systems, including Space Station experiments, Orbiter Transfer Vehicles, and Space Materials Processing. The ACIP system has been developed for the NASA Johnson Space Center.

ACIP/PCM/HIRAP CHARACTERISTICS TABLE
ACIP
• 3 Linear Accelerometer Sensors • 3 Angular Accelerometer Sensors • 3 Rate Gyro Sensors • Handles data from 6 control surfaces
HIRAP
• 3 High Resolution Accelerometers • Fine and Coarse Temperature Sensors • Accurate to One Micro-g
PCM
• Operates at 64 Kbps • Up to 512 addressable channels • Four selectable bit rates (16, 32, 64, 128 Kbps) • Master/slave unit, up to 4 slaves • Serial data/address transmission master master to slave

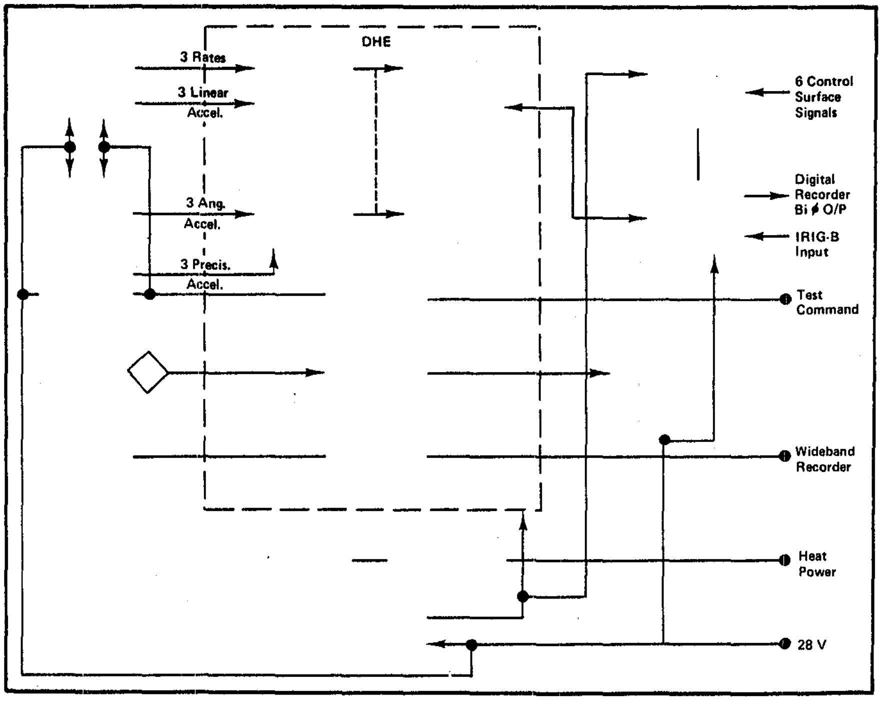
–A Sensor System

ACIP/PCM/HIRAP

The ACIP is an orthogonal 3-axis sensor system which is made up of 3 hydrostatic suspension single degree of freedom rate gyros, 3 force balance linear accelerometers (TAGIP) and 3 single axis, fluid rotor (TAA) angular accelerometers. The HIRAP provides 3 orthogonal, pendulous proof-mass, force rebalanced precision linear accelerometers to the Shuttle data acquisition system.

The analog outputs of these sensors are presample filtered, multiplexed and converted to a serial digitial format. Included in this format is the data from 6 control surface sensors which are correlated with data from the 3 axis sensor system.

ACIP SENSOR PARAMETERS			
Unit	**Space Direction**	**Range**	**Sensor Resolution**
Linear Accelerometer	X-Axis (Longitudinal)	± 1.5g	150 μg
	Y-Axis (Lateral)	± 0.5g	50 μg
	Z-Axis (Normal)	± 3.0g	300 μg
Angular Accelerometer	X-Axis (Roll)	$\pm 2.0\ r/s^2$	$240\ \mu r/s^2$
	Y-Axis (Pitch)	$\pm 1.0\ r/s^2$	$120\ \mu r/s^2$
	Z-Axis (Yaw)	$\pm 1.0\ r/s^2$	$120\ \mu r/s^2$
Rate Gyro	X-Axis (Roll)	$\pm 30.0^0/s$	$.003^0/s$
	Y-Axis (Pitch)	$\pm 10.0^0/s$	$.001^0/s$
	Z-Axis (Yaw)	$\pm 10.0^0/s$	$.001^0/s$
Micro-g Linear Accelerometer	X-Axis (Roll)	± 8.0 milli-g	1.0 μg
	Y-Axis (Pitch)	± 8.0 milli-g	1.0 μg
	Z-Axis (Yaw)	± 8.0 milli-g	1.0 μg

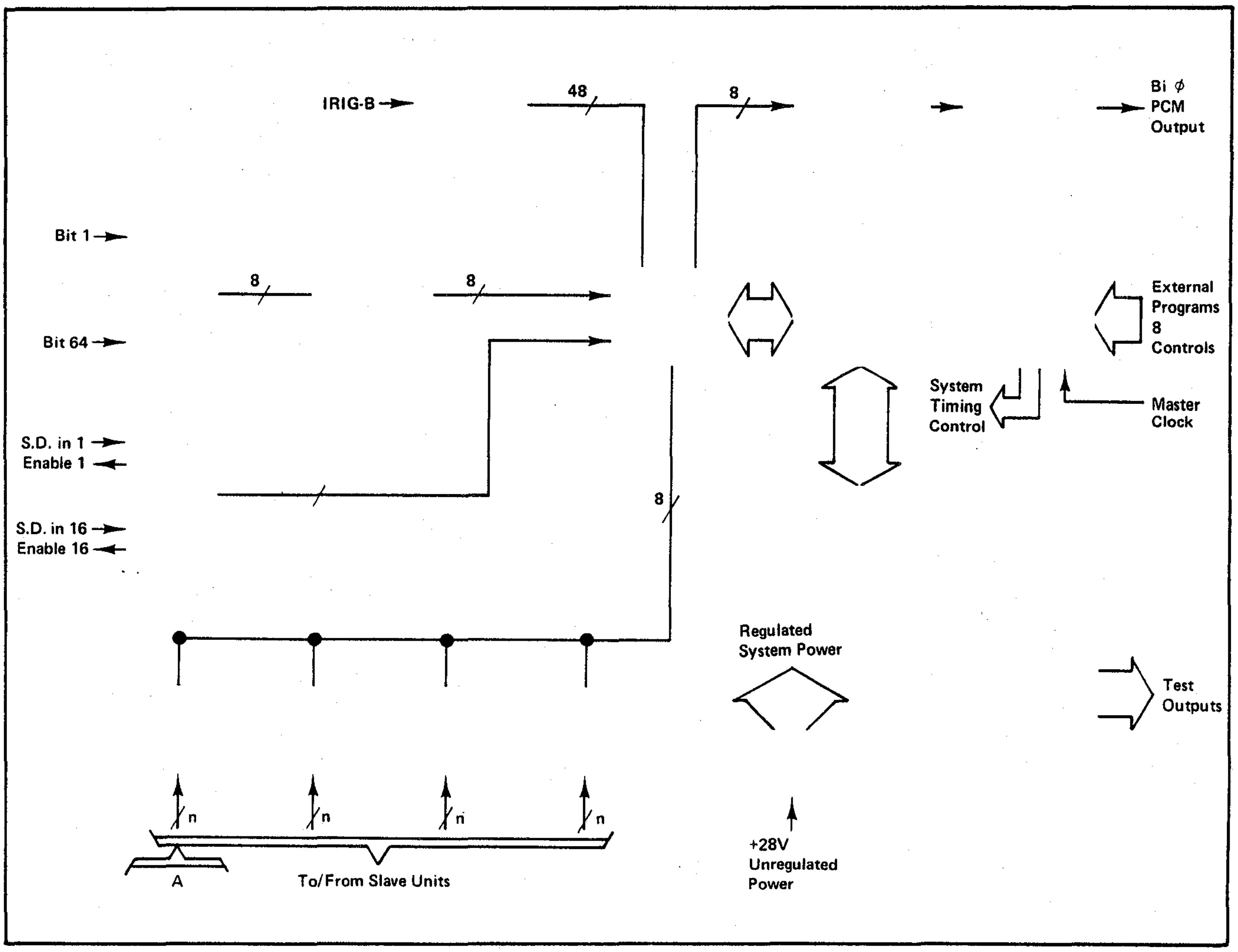


The merged sensor digital data is transferred to the Orbiter Experiment system tape recorders via the PCM master unit serial Bi-phase output.

Fourteen bit A/D conversion is performed at selectable rates up to 8000 words/sec. By using a special design technique in conjunction with the IRIG-B time code, the time of any sample can be resolved to 0.1 msec.

ACIP/PCM ...Accommodates Four Experiments

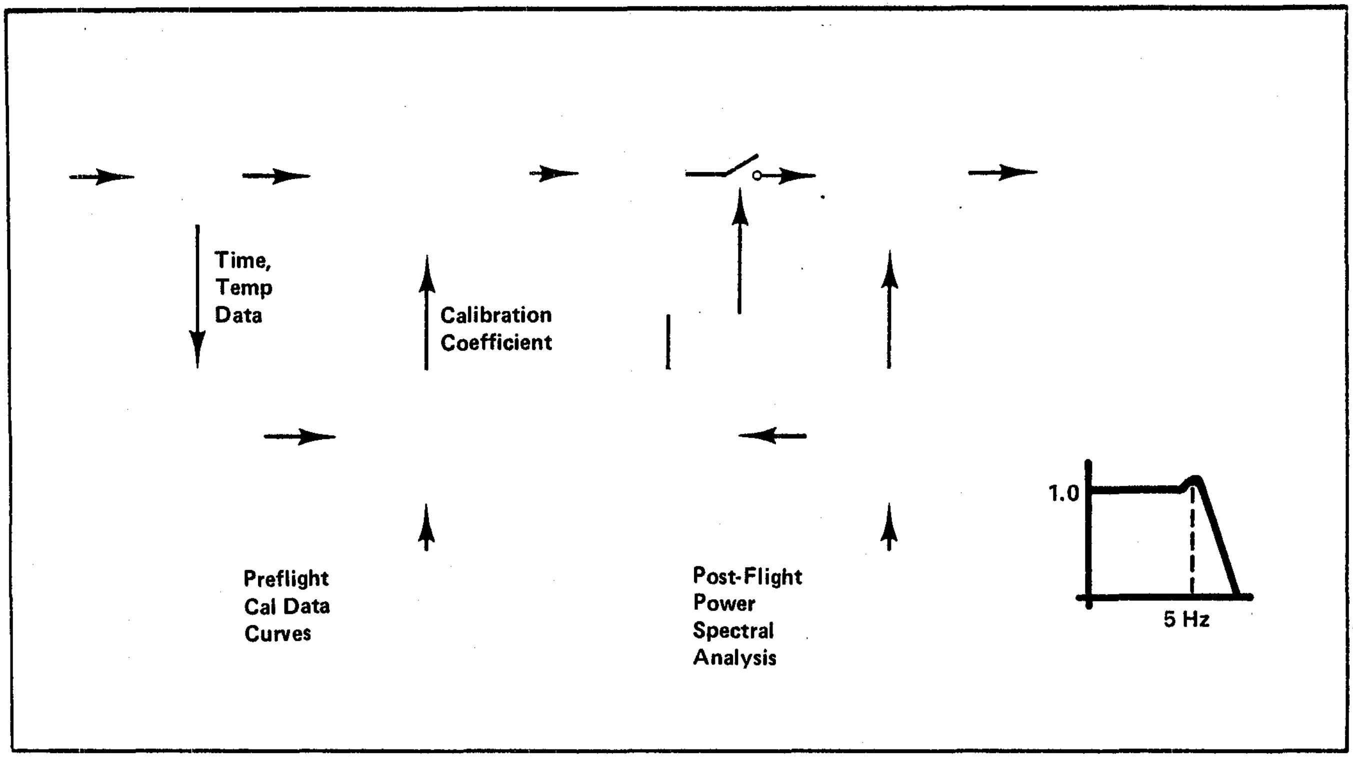
The PCM is a master-slave system capable of supporting up to four slaves. Each slave constitutes a remote data collection terminal controlled by the resident master format program. Slave subsystems are responsible for their own power conditioning, analog and digital multiplexing, analog to digital and parallel to serial conversion, as well as for decoding of addresses, and format control and storage. Selectable bit rate clocks and all control signals necessary for proper operation of slaves are contained in the master unit.



–Data Processing

ACIP/PCM/HIRAP

...Operational Sequence



FLIGHT OPERATIONS

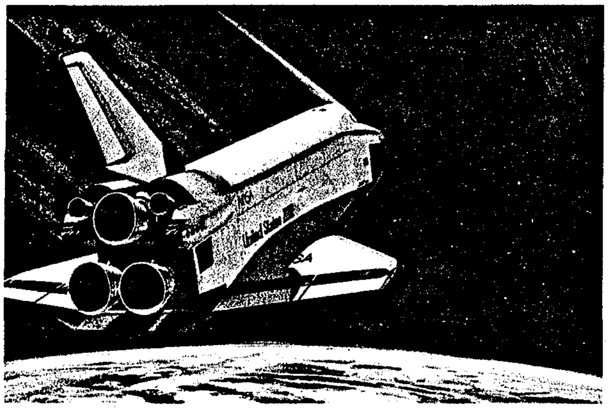
Prior to the Shuttle orbiter reentry phase, two manual in-flight functional tests are performed. The first measures the ambient inertial variable date near the sensor's null state. The second verifies the sensor's servo loop operation at selected points over the full scale dynamic range.

During the reentry phase minimum crew involvement is required to operate the ACIP/PCM/HIRAP. At approximately 400 to 450 Kft altitude, a command from the ACIP Orbiter Interface activates the ACIP/PCM/HIRAP system.

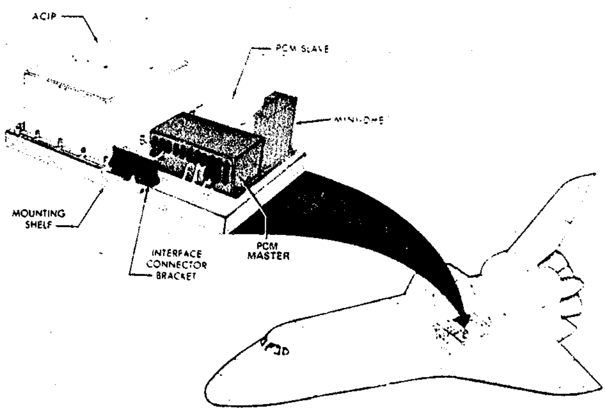
DATA MEASUREMENT AND DATA REDUCTION

Data measurements are obtained by sampling sensor outputs at a high rate after analog filtering. The data tapes are then transferred to the ground Orbiter Experiment Systems Analysis Laboratory for engineering unit conversion and sensor temperature logging. By using stored calibration, corrections are implemented before Finite Pulse Response digital filtering. This entire process results in a flexible, non-critical system with a dynamic range of 10,000:1 or greater.

— Aerospace Advanced Instrument Systems —



Space Shuttle Orbiter



Aerodynamic Coefficient Identification Package

KMS Fusion has developed and acquired significant capabilities in several technological areas that are directly applicable to NASA and DOD. These technologies include advanced instrumentation, lasers, optics, materials development and microfabrication techniques. In addition, KMSF has the capability to support its research and development with sophisticated engineering, computation and test facilities.

KMS Fusion offers total systems capability to provide a broad spectrum of technical skills and experience encompassing all of the engineering and scientific disciplines required to develop and deliver end-to-end systems as well as an experienced program management team to guide the engineering effort through all program phases from concept development to production support.

Future programs we are working on at KMSF for the Space Shuttle and proposed NASA Space Station include advanced inertial instrumentation, laser and optical instrumentation, space material manufacturing and processing, and potential microfabrication and biotechnology applications experiments.

kms

inc.
Ann Arbor, Michigan

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APPENDIX F

Surface Tension Induced Convection

Safety Hazard Reports

This appendix gives the Payload Safety Matrix and Payload Hazard Reports prepared for this experiment.

PAYLOAD SAFETY MATRIX

PAYLOAD	PAYLOAD ORGANIZATION	DATE	PAGE
Surface Tension Driven Convection Exp.		2 Dec. 1982	

HAZARD GROUP / SUBSYSTEM	COLLISION	CONTAMINATION (TOXICITY, ETC)	CORROSION	ELECTRICAL SHOCK	EXPLOSION	FIRE	INJURY AND ILLNESS	LOSS OF ENTRY CAPABILITY	RADIATION	TEMPERATURE EXTREMES								
Biomedical																		
Hazard Detection and Safing*																		
Cryogenics																		
Electrical		X			X	X				X								
Environmental Control		X																
Human Factors		X		X			X											
Hydraulics																		
Materials	X	X	X			X												
Mechanical																		
Optical																		
Pressure Systems																		
Propulsion																		
Pyrotechnics																		
Radiation																		
Structures	X						X											

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PAYLOAD HAZARD REPORT

PAYLOAD Surface Tension Driven Convection Experiment	**NO.** STDC-1 **PHASE** 0
SUBSYSTEM Electrical	**DATE** 2 December 1982

HAZARD TITLE
Temperature Extreme - Heater Runaway

APPLICABLE SAFETY REQUIREMENTS: NHB 1700.7A, Safety Policy and Requirements for Payloads Using the Space Transportation System (STS), paragraphs 201, Failure Tolerance, 201.2, Catastrophic Hazards and 213, Electrical Systems.

DESCRIPTION OF HAZARD:

Inadvertent heater activation resulting in over-temperature of experimental fluid with possible over-pressure and release to manned environment of fluid/vapor.

HAZARD CAUSES:

1. Loss of heater control.

HAZARD CONTROLS:

SAFETY VERIFICATION METHODS:

STATUS:

CONCURRENCE	PHASE I	PHASE II
Payload Organization		
STS Operator		

APPROVAL	PHASE III
Payload Organization	STS Operator

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PAYLOAD HAZARD REPORT

NO.	STDC-2
PAYLOAD: Surface Tension Driven Convection Experiment	PHASE: 0
SUBSYSTEM: Electrical	DATE: 2 December 1982

HAZARD TITLE: Temperature Extreme - High Heater Current

APPLICABLE SAFETY REQUIREMENTS: NHB 1700.7A, Safety Policy and Requirements for Payloads Using the Space Transportation System (STS), paragraphs 201, Failure Tolerance, 201.2, Catastrophic Hazards and 213, Electrical Systems.

DESCRIPTION OF HAZARD:

Inadvertant failure of heater control allowing heater element to receive excessive current resulting in over-temperature of experimental fluid with possible over-pressure and release to manned environment of fluid/vapor.

HAZARD CAUSES:

1. Heater Control(s) failure.

HAZARD CONTROLS:

SAFETY VERIFICATION METHODS:

STATUS:

CONCURRENCE	PHASE I	PHASE II
Payload Organization		
STS Operator		

APPROVAL	PHASE III
Payload Organization	STS Operator

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PAYLOAD HAZARD REPORT	NO. STDC-3
PAYLOAD: Surface Tension Driven Convection Experiment	PHASE: 0
SUBSYSTEM: Electrical	DATE: 2 December 1982

HAZARD TITLE: Fire-Ignition of Flammable Atmospheres

APPLICABLE SAFETY REQUIREMENTS: NHB 1700.7A, Safety Policy and Requirements for Payloads Using the Space Transportation System (STS), paragraph 219, Flammable Atmospheres.

DESCRIPTION OF HAZARD: Short circuit, electrical sparks, electrical or mechanical failures causing high temperature buildup within vicinity of flammable atmospheres resulting in ignition of flammable atmosphere and the production of smoke, contaminants, toxic fumes and fire.

HAZARD CAUSES:

1. Short circuits.
2. Circuit overloads.
3. Mechanical component freezing up or failing.
4. Arcing or sparking.
5. Poor grounding.

HAZARD CONTROLS:

SAFETY VERIFICATION METHODS:

STATUS:

CONCURRENCE	PHASE I	PHASE II
Payload Organization		
STS Operator		

APPROVAL	PHASE III
Payload Organization	STS Operator

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PAYLOAD HAZARD REPORT

NO.	STDC-4
PAYLOAD Surface Tension Driven Convection Experiment	**PHASE** 0
SUBSYSTEM Environmental Control	**DATE** 2 December 1982

HAZARD TITLE: Contamination - Inert Gas Escaping into Manned Environment

APPLICABLE SAFETY REQUIREMENTS: NHB 1700.7A, Safety Policy and Requirements for Payloads Using the Space Transportation System (STS), paragraph 201, Failure Tolerance.

DESCRIPTION OF HAZARD:

Failure of experiment container to isolate vapor of experimental fluid from manned environment.

HAZARD CAUSES:

1. Faulty non-redundant seals.
2. Shattering of experiment container.

HAZARD CONTROLS:

SAFETY VERIFICATION METHODS:

STATUS:

CONCURRENCE	PHASE I	PHASE II
Payload Organization		
STS Operator		

APPROVAL	PHASE III
Payload Organization	STS Operator

PAYLOAD HAZARD REPORT

NO.	STDC-5
PAYLOAD: Surface Tension Driven Convection Experiment	PHASE: 0
SUBSYSTEM: Human Factors	DATE: 2 December 1982

HAZARD TITLE:
Injury - General

APPLICABLE SAFETY REQUIREMENTS: NHB 1700.7A, Safety Policy and Requirements for Payloads Using the Space Transportation System (STS), paragraph 201, Failure Tolerance

DESCRIPTION OF HAZARD:
Injury to personnel due to sharp corners, protruding equipment, accessible high temperature surfaces, dangerous procedures, and improperly restrained drawers.

HAZARD CAUSES:

1. Failure to meet the requirements of MIL-STD-1472C, Human Engineering Design Criteria for Military Systems, Equipment and Facilities.

HAZARD CONTROLS:

SAFETY VERIFICATION METHODS:

STATUS:

CONCURRENCE	PHASE I	PHASE II
Payload Organization		
STS Operator		

APPROVAL	PHASE III
Payload Organization	STS Operator

PAYLOAD HAZARD REPORT	NO. STDC-6
PAYLOAD: Surface Tension Driven Convection Experiment	PHASE: 0
SUBSYSTEM: Human Factors	DATE: 2 December 1982
HAZARD TITLE: Contamination-Release of Glass Particles to Manned Environment	

APPLICABLE SAFETY REQUIREMENTS: NHB 1700.7A, Safety Policy and Requirements for Payloads Using the Space Transportation System (STS), paragraphs 201, Failure Tolerance and 206, Failure Propagation.

DESCRIPTION OF HAZARD:

Shattering of glass lenses, fluid containers, and light bulbs by temperature transients, vibration and collision, causing injury to personnel.

HAZARD CAUSES:

1. Changes in temperature which could cause fracture.
2. Defective parts.
3. Shock during ground loading.
4. Unshielded shatterable materials.

HAZARD CONTROLS:

SAFETY VERIFICATION METHODS:

STATUS:

CONCURRENCE	PHASE I	PHASE II
Payload Organization		
STS Operator		

APPROVAL	PHASE III
Payload Organization	STS Operator

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PAYLOAD HAZARD REPORT

NO.	STDC-7
PAYLOAD: Surface Tension Driven Convection Experiment	PHASE: 0
SUBSYSTEM: Human Factors	DATE: 2 December 1982
HAZARD TITLE: Electrical Shock - General	

APPLICABLE SAFETY REQUIREMENTS: NHB 1700.7A, Safety Policy and Requirements for Payloads Using the Space Transportation System (STS), paragraphs 201, Failure Tolerance and 213, Electrical Systems.

DESCRIPTION OF HAZARD:
Injury to flight personnel due to electric shock during contact with control panel.

HAZARD CAUSES:

1. Improperly secured or vibrated loose connectors.
2. Defective connectors.
3. Improper grounding.
4. Improper fusing.

HAZARD CONTROLS:

SAFETY VERIFICATION METHODS:

STATUS:

CONCURRENCE	PHASE I	PHASE II
Payload Organization		
STS Operator		

APPROVAL	PHASE III
Payload Organization	STS Operator

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PAYLOAD HAZARD REPORT	NO. STDC-8
PAYLOAD: Surface Tension Driven Convection Experiment	PHASE: 0
SUBSYSTEM: Materials	DATE: 2 December 1982
HAZARD TITLE: Contamination - Toxic Fumes	

APPLICABLE SAFETY REQUIREMENTS: NHB 1700.7A, Safety Policy and Requirements for Payloads Using the Space Transportation System (STS), paragraph 209.1, Hazardous Materials.

DESCRIPTION OF HAZARD:

Non-compatibility of photographic film with a failure induced environment, causing a release of toxic fumes and/or fire.

HAZARD CAUSES:

1. Photographic film capable of discharging toxic fumes in a failure induced environment.

HAZARD CONTROLS:

SAFETY VERIFICATION METHODS:

STATUS:

CONCURRENCE	PHASE I	PHASE II
Payload Organization		
STS Operator		

APPROVAL	PHASE III
Payload Organization	STS Operator

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PAYLOAD HAZARD REPORT	NO. STDC-9
PAYLOAD Surface Tension Driven Convection Experiment	PHASE 0
SUBSYSTEM Materials	DATE 2 December 1982

HAZARD TITLE Contamination-Electric Motors

APPLICABLE SAFETY REQUIREMENTS: NHB 1700.7A, Safety Policy and Requirements for Payloads Using the Space Transportation (STS), paragraphs 201, Failure Tolerance, 202, Control of Hazardous Functions and 209.3, Flammable Materials.

DESCRIPTION OF HAZARD:

Jammed electric motors can cause overheating resulting in melting and/or burning of material (insulation, bearing lubricant) which leads to the production of smoke, contaminants, and toxic fumes.

HAZARD CAUSES:

Use of flammable materials.

HAZARD CONTROLS:

SAFETY VERIFICATION METHODS:

STATUS:

CONCURRENCE	PHASE I	PHASE II
Payload Organization		
STS Operator		

APPROVAL	PHASE III
Payload Organization	STS Operator

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PAYLOAD HAZARD REPORT

PAYLOAD: Surface Tension Driven Convection Experiment	**NO.** STDC-10
SUBSYSTEM: Materials	**PHASE:** 0
	DATE: 2 December 1982
HAZARD TITLE: Stress Corrosion Induced Failures	

APPLICABLE SAFETY REQUIREMENTS: NHB 1700.7A, Safety Policy and Requirements for Payloads Using the Space Transportation System (STS), paragraph 208.3, Stress Corrosion.

DESCRIPTION OF HAZARD:

Failure of metal structures and parts due to stress (intergranular) corrosion allowing weakened structures to become flying projectiles.

HAZARD CAUSES:

1. Use of materials not meeting the requirements of MSFC-SPEC-522A.
2. Manufacturing stresses.

HAZARD CONTROLS:

SAFETY VERIFICATION METHODS:

STATUS:

CONCURRENCE	PHASE I	PHASE II
Payload Organization		
STS Operator		

APPROVAL	PHASE III
Payload Organization	STS Operator

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PAYLOAD HAZARD REPORT	NO. STDC-11
PAYLOAD Surface Tension Driven Convection Experiment	PHASE 0
SUBSYSTEM Materials	DATE 2 December 1982

HAZARD TITLE Contamination-Film

APPLICABLE SAFETY REQUIREMENTS: NHB 1700.7A, Safety Policy and Requirements for Payloads Using the Space Transportation System (STS), paragraphs 201, Failure Tolerance, 202, Control of Hazardous Functions and 209.3, Flammable Materials.

DESCRIPTION OF HAZARD:

Jammed rotating members can cause overheating resulting in melting and/or burning of material (film) which leads to the production of smoke, contaminants, and toxic fumes.

HAZARD CAUSES:

1. Use of flammable materials.

HAZARD CONTROLS:

SAFETY VERIFICATION METHODS:

STATUS:

CONCURRENCE	PHASE I	PHASE II
Payload Organization		
STS Operator		

APPROVAL	PHASE III
Payload Organization	STS Operator

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PAYLOAD HAZARD REPORT

NO.	STDC-12
PAYLOAD Surface Tension Driven Convection Experiment	**PHASE** 0
SUBSYSTEM Structures	**DATE**

HAZARD TITLE Projectiles

APPLICABLE SAFETY REQUIREMENTS: NHB 1700.7A, Safety Policy and Requirements for Payloads Using the Space Transportation System (STS), paragraphs 208.1, Structural Design and 208.2, Emergency Landing Loads.

DESCRIPTION OF HAZARD:

Injury to personnel caused by failed structures or securing hardware allowing objects to become projectiles.

HAZARD CAUSES:

1. Appropriate safety factors not applied.
2. Propagation of a pre-existing flaw in the materials used.

HAZARD CONTROLS:

SAFETY VERIFICATION METHODS:

STATUS:

CONCURRENCE	PHASE I	PHASE II
Payload Organization		
STS Operator		

APPROVAL	PHASE III
Payload Organization	STS Operator

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APPENDIX G

Free Surface Phenomena
Safety Reports

This appendix contains the Payload Safety Matrix and the Payload Hazard reports for this experiment.

PAYLOAD SAFETY MATRIX

PAYLOAD	PAYLOAD ORGANIZATION	DATE	PAGE
Free Surface Phenomena Exp.		2 Dec.1982	

HAZARD GROUP / SUBSYSTEM	COLLISION	CONTAMINATION (TOXICITY, ETC)	CORROSION	ELECTRICAL SHOCK	EXPLOSION	FIRE	INJURY AND ILLNESS	LOSS OF ENTRY CAPABILITY	RADIATION	TEMPERATURE EXTREMES								
Biomedical																		
Hazard Detection and Safing*																		
Cryogenics																		
Electrical		X				X												
Environmental Control		X																
Human Factors		X		X			X											
Hydraulics																		
Materials	X	X	X			X												
Mechanical																		
Optical																		
Pressure Systems																		
Propulsion																		
Pyrotechnics																		
Radiation																		
Structures	X						X											

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PAYLOAD HAZARD REPORT	NO. FSPE-1
PAYLOAD: Free Surface Phenomena Experiment	PHASE: 0
SUBSYSTEM: Electrical	DATE: 2 December 1982

HAZARD TITLE: Fire-Ignition of Flammable Atmospheres

APPLICABLE SAFETY REQUIREMENTS: NHB 1700.7A, Safety Policy and Requirements for Payloads Using the Space Transportation System (STS), paragraph 219, Flammable Atmospheres.

DESCRIPTION OF HAZARD:
Short circuit, electrical sparks, electrical or mechanical failures causing high temperature buildup within vicinity of flammable atmospheres resulting in ignition of flammable atmosphere and the production of smoke, contaminants, toxic fumes and fire.

HAZARD CAUSES:

1. Short circuits.
2. Circuit overloads.
3. Mechanical component freezing up or failing.
4. Arcing or sparking.
5. Poor grounding.

HAZARD CONTROLS:

SAFETY VERIFICATION METHODS:

STATUS:

CONCURRENCE	PHASE I	PHASE II
Payload Organization		
STS Operator		

APPROVAL	PHASE III
Payload Organization	STS Operator

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PAYLOAD HAZARD REPORT	NO. FSPE-2
PAYLOAD: Free Surface Phenomena Experiment	PHASE: 0
SUBSYSTEM: Environmental Control	DATE: 2 December 1982

HAZARD TITLE: Contamination - Inert Gas Escaping into Manned Environment

APPLICABLE SAFETY REQUIREMENTS: NHB 1700.7A, Safety Policy and Requirements for Payloads Using the Space Transportation System (STS), paragraph 201, Failure Tolerance.

DESCRIPTION OF HAZARD:

Failure of experiment container to isolate vapor of experimental fluid from manned environment.

HAZARD CAUSES:

1. Faulty non-redundant seals.
2. Shattering of experiment container.

HAZARD CONTROLS:

SAFETY VERIFICATION METHODS:

STATUS:

CONCURRENCE	PHASE I	PHASE II
Payload Organization		
STS Operator		

APPROVAL	PHASE III
Payload Organization	STS Operator

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PAYLOAD HAZARD REPORT	NO. FSPE-3
PAYLOAD: Free Surface Phenomena Experiment	PHASE: 0
SUBSYSTEM: Human Factors	DATE: 2 December 1982

HAZARD TITLE: Injury - General

APPLICABLE SAFETY REQUIREMENTS: NHB 1700.7A, Safety Policy and Requirements for Payloads Using the Space Transportation System (STS), paragraph 201, Failure Tolerance.

DESCRIPTION OF HAZARD: Injury to personnel due to sharp corners, protruding equipment, accessible high temperature surfaces, dangerous procedures, and improperly restrained drawers.

HAZARD CAUSES:

1. Failure to meet the requirements of MIL-STD-1472C, Human Engineering Design Criteria for Military Systems, Equipment and Facilities.

HAZARD CONTROLS:

SAFETY VERIFICATION METHODS:

STATUS:

CONCURRENCE	PHASE I	PHASE II
Payload Organization		
STS Operator		

APPROVAL	PHASE III
Payload Organization	STS Operator

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PAYLOAD HAZARD REPORT	NO. FSPE-4
PAYLOAD: Free Surface Phenomena Experiment	PHASE: 0
SUBSYSTEM: Human Factors	DATE: 2 December 1982

HAZARD TITLE: Contamination-Release of Glass Particles to Manned Environment

APPLICABLE SAFETY REQUIREMENTS: NHB 1700.7A, Safety Policy and Requirements for Payloads Using the Space Transportation System (STS), paragraphs 201, Failure Tolerance and 206, Failure Propagation.

DESCRIPTION OF HAZARD:

Shattering of glass lenses, fluid containers, and light bulbs by vibration and collision, causing injury to personnel.

HAZARD CAUSES:

1. Changes in temperature which could cause fracture.
2. Defective parts.
3. Shock during ground loading.
4. Unshielded shatterable materials.

HAZARD CONTROLS:

SAFETY VERIFICATION METHODS:

STATUS:

CONCURRENCE	PHASE I	PHASE II
Payload Organization		
STS Operator		

APPROVAL	PHASE III
Payload Organization	STS Operator

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PAYLOAD HAZARD REPORT

NO.	FSPE-5
PAYLOAD: Free Surface Phenomena Experiment	PHASE: 0
SUBSYSTEM: Human Factors	DATE: 2 December 1982

HAZARD TITLE: Electrical Shock - General

APPLICABLE SAFETY REQUIREMENTS: NHB 1700.7A, Safety Policy and Requirements for Payloads Using the Space Transportation System (STS), paragraphs 201, Failure Tolerance and 213, Electrical Systems.

DESCRIPTION OF HAZARD: Injury to flight personnel due to electric shock during contact with control panel.

HAZARD CAUSES:

1. Improperly secured or vibrated loose connectors.
2. Defective connectors.
3. Improper grounding.
4. Improper fusing.

HAZARD CONTROLS:

SAFETY VERIFICATION METHODS:

STATUS:

CONCURRENCE	PHASE I	PHASE II
Payload Organization		
STS Operator		

APPROVAL	PHASE III
Payload Organization	STS Operator

PAYLOAD HAZARD REPORT	NO. FSPE-6
PAYLOAD: Free Surface Phenomena Experiment	PHASE: 0
SUBSYSTEM: Materials	DATE: 2 December 1982

HAZARD TITLE: Contamination - Toxic Fumes

APPLICABLE SAFETY REQUIREMENTS: NHB 1700.7A, Safety Policy and Requirements for Payloads Using the Space Transportation System (STS), paragraph 209.1, Hazardous Materials.

DESCRIPTION OF HAZARD:

Non-compatibility of photographic film with a failure induced environment, causing a release of toxic fumes and/or fire.

HAZARD CAUSES:

1. Photographic film capable of discharging toxic fumes in a failure induced environment.

HAZARD CONTROLS:

SAFETY VERIFICATION METHODS:

STATUS:

CONCURRENCE	PHASE I	PHASE II
Payload Organization		
STS Operator		

APPROVAL	PHASE III	
Payload Organization	STS Operator	

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PAYLOAD HAZARD REPORT	NO. FSPE-7
PAYLOAD: Free Surface Phenomena Experiment	PHASE: 0
SUBSYSTEM: Materials	DATE: 2 December 1982

HAZARD TITLE: Stress Corrosion Induced Failures

APPLICABLE SAFETY REQUIREMENTS: NHB 1700.7A, Safety Policy and Requirements for Payloads Using the Space Transportation System (STS), paragraph 208.3, Stress Corrosion.

DESCRIPTION OF HAZARD:

Failure of metal structures and parts due to stress (intergranular) corrosion allowing weakened structures to become flying projectiles.

HAZARD CAUSES:

1. Use of materials not meeting the requirements of MSFC-SPEC-522A.
2. Manufacturing stresses.

HAZARD CONTROLS:

SAFETY VERIFICATION METHODS:

STATUS:

CONCURRENCE	PHASE I	PHASE II
Payload Organization		
STS Operator		

APPROVAL	PHASE III
Payload Organization	STS Operator

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PAYLOAD HAZARD REPORT

NO.	FSPE-8
PAYLOAD: Free Surface Phenomena Experiment	PHASE: 0
SUBSYSTEM: Materials	DATE: 2 December 1982

HAZARD TITLE: Contamination-Film

APPLICABLE SAFETY REQUIREMENTS: NHB 1700.7A, Safety Policy and Requirements for Payloads Using the Space Transportation System (STS), paragraphs 201, Failure Tolerance, 202, Control of Hazardous Functions and 209.3, Flammable Materials.

DESCRIPTION OF HAZARD:

Jammed rotating members can cause overheating resulting in melting and/or burning of material (film) which leads to the production of smoke, contaminants, and toxic fumes.

HAZARD CAUSES:

1. Use of flammable materials.

HAZARD CONTROLS:

SAFETY VERIFICATION METHODS:

STATUS:

CONCURRENCE	PHASE I	PHASE II
Payload Organization		
STS Operator		

APPROVAL	PHASE III
Payload Organization	STS Operator

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